NASA'S LONG-RANGE GOALS

HEARING

BEFORE THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

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*Ranking Republican Member.
**Resigned February 19, 1987 (H. Res. 89).
***Elected March 30, 1987 (H. Res. 133).

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NASA'S LONG-RANGE GOALS

WEDNESDAY, JULY 22, 1987

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, DC.

The subcommittee met, pursuant to call, at 11:08 a.m., in room 2325, Rayburn House Office Building, Hon. Bill Nelson (chairman of the subcommittee) presiding.

Mr. NELSON. Good morning.

We are going to begin a series of hearings on NASA's long-range goals, and by the interest exhibited here today with your presence, it's obviously a subject that we all need to tend to.

We expect to be spending a great deal of time looking at this issue over the next several months because now is the time of a critical decision-making juncture for America's space program.

Since the end of the Apollo program, we have needed some major goal, a goal that would lead to technological advances, that would provide new scientific and intellectual stimulation, a goal that would clearly reassert our international leadership. Over the last decade, the budget for the space effort has fallen to less than half what it was in the mid-1960s, and our science and exploration program now are at a bare subsistence level. So the space program that once united the dreamers with the doers has made way to the world of the budgeteers.

So now, as we rebuild from the *Challenger* accident, we are in greater need than ever before to focus on the future. I know that the men and women who have dedicated their careers to our space program have not lost their sense of purpose. That is obvious, day in and day out, as we rebuild. These folks stand ready to be our greatest resource if the administration, specifically the President, and the Congress can provide the leadership necessary to get back on track.

Now, on this note, let me pause to express my great disappointment at the administration for it seeing fit to delay the release of NASA's response to the Paine Commission, the National Commission on Space. In 1985, this committee, through the NASA authorization bill, set up the National Commission on Space. That Commission, headed by a former NASA Administrator, Dr. Tom Paine, rendered an extraordinarily visionary report. In part, that report got lost by virtue of the timing that we had the terrible tragedy that we all suffered. But this committee has constantly sought—in fact, through law, through the NASA authorization bill—to get NASA to come forth with a response to the National Commission

on Space. The National Commission on Space reported over a year ago, and we still do not have NASA's response to it.

Last Monday, the front page of the Washington Post contained headlines that proclaimed that the Soviets are making steady gains in space due to their tried-and-true technology and their willingness to take greater risk. Now we must be willing to take greater risk—not risks to life but risks in our national commitment to a future space program. We cannot let the present budgetary difficulties be so preoccupying that we cannot look beyond the immediate horizons.

Well, today we're going to look beyond those horizons, thanks to Sally. We're going to hear from Dr. Ride, who has recently completed a study of four major initiatives in space that can be undertaken over the next 20 years. Now, this is the kind of thinking that ought to be given some high visibility. This is the kind of thinking that ought to have been given the high visibility on the Paine Commission report, and so we're going to try again.

What we want is widespread public debate about these initiatives. We don't want this to get buried in some bureaucratic maze in the Office of Management and Budget or the OSTP, or the Economic Policy Council, or any of these other organizations who love to get their fingers into the national space program. The American people deserve to hear the thoughts of their leaders on the future of our space program. So, Dr. Ride, we look forward to your testimony.

I want to call on my colleauge, Mr. Walker, our ranking member, for his comments.

Mr. WALKER. Thank you, Mr. Chairman.

I have a fairly lengthy statement here that I would ask unanimous consent that it be considered in the——

Mr. NELSON. Without objection.

Mr. WALKER. Just let me make a couple of comments here at the outset.

Today we are going to hear from Dr. Ride about four possible initiatives that will carry us into the next session—into the next century. They are imaginative missions, but even they are not really a long-term program goal. What we need to teach the American public is that this program doesn't spend money in space; what we do is we create jobs through space activities. We develop technology that keeps the American economy strong. We bolster American competitiveness abroad, provide American leadership throughout the world in science and technology.

As you look around this room today, you see examples of American accomplishments in space so far. We all remember the pride Americans took in each success that has been represented here today. Let's start today to build a consensus in this Congress and in America that will establish real goals for our Nation's future.

[The prepared opening statement of Mr. Walker follows:]

OPENING REMARKS OF

REPRESENTATIVE ROBERT S. WALKER

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

JULY 22, 1987

Good morning. I want to join the Chairman in extending a warm welcome to Dr. Sally Ride, on this, her final appearance before the committee as an official NASA witness.

This is a very important hearing that we are holding today. NASA has been an agency in the doldrums. Following the tragic loss of the Space Shuttle Challenger in January of last year, and the series of accidents that have plagued the few remaining expendable launch vehicles, NASA has lost virtually all of the momentum that had carried us forward into what had appeared to be a bright space future for America.

I must admit that I am deeply concerned over the direction that NASA appears to be headed. This agency was established with the clear mission to be conducting cutting-edge research and development. This is an agency that was expected to be always extending the frontiers of our knowledge further and further into the unknown. But the perception on this Committee is that NASA is becoming mired in the day-to-day operational problems of operating the space shuttle system, of procuring ELV services to launch existing payloads, and finally, in the development of the space station. The Committee obviously supports each of these programs, and they are all important. But, they appear to be

a limitless sponge soaking up all of the resources that are available in current, and projected budgets.

The problem that faces this committee is that we are constrained by the Gramm-Rudman-Hollings restraints. We cannot add money to a program that we realize is not adequately funded. We are forced to defend the President's request level, and this year we had to fight vigorously on the floor to avoid having $155 million cut from the NASA bill to meet the unrealistic budget resolution adopted by the majority of the House Democrats. Under the present budget system we are forced to argue at great length as to whether the appropriate funding level for NASA is 9.5 or 9.6 billion dollars a year, when the real debate should be on exactly what kind of a space program the American people want and need, and how much money they are willing to spend to accomplish the national space goals?

We have about a year until our next manned launch. I sense that most Americans do support our space program, but that support is not clearly focused because NASA is not focused on long-term goals. I think that we need to start right now to build a consensus that will lead to a political understanding that NASA must receive adequate funding to accomplish the goals we set for ourselves.

One of the most distressing things about the problem that faces us today is that we see the continuing unwillingness of the Office of Management and Budget to even consider the importance of long-term stability in the NASA

program. The exploration of space is a critical element in the creation of a space-based economy in the coming decades. We have already seen the early signs that advanced technologies will lead to advances in the fields of health care, materials sciences, and dozens of other technologies. Those advances, however, will require stability in the NASA program that comes from the pursuit of long-term goals and funding profiles that allow research to move forward without the constant threat of cuts to support operational activities.

Two years ago, in direct response to these concerns, this Committee included the authorization for the National Commission on Space in our NASA authorization bill. That Commission completed its report a year ago. We still see no signs that OMB is willing even to consider supporting even a small part of the Commission recommendations.

Today we will hear Dr. Sally Ride present four possible initiatives that would carry us into the next century. They are imaginative missions, but even they are not a long-term program goal.

We need to teach the American public that this program does not spend money in space, we create jobs throughout the country. We develop the technology that keeps the American economy strong. We bolster American competitiveness abroad. And we provide American leadership throughout the world in science and technology. As you look around this room today you see examples of American accomplishments in space so far.

We all remember the pride Americans took in each success represented here. Let us start today to build the consensus that will establish the goals for future.

Mr. NELSON. Thank you, Mr. Walker.
Dr. Ride.

STATEMENT OF DR. SALLY K. RIDE, ACTING ASSISTANT ADMINISTRATOR, OFFICE OF EXPLORATION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY ALAN M. LADWIG

Dr. RIDE. Thank you very much, and thank you for the opportunity to come and speak to your subcommittee.

I do have a prepared statement that I would like to submit for the record. If it's all right with you, I would just as soon summarize that statement and then respond to your specific questions in your letter to me on descriptions of the initiatives which were a part of the study, but by no means the whole study, that my group has been undertaking for the past several months.

Mr. NELSON. Please proceed.

Dr. RIDE. I guess my first comment is that the report is not quite complete. We're putting the finishing touches on it right now. It has not been delivered to Dr. Fletcher, the NASA Administrator, yet. It probably will be some time during the first week in August, and so you'll have to bear with me. I don't feel free to discuss the conclusions of that report since I have not had a chance to submit it to my boss yet. But I am happy to come and discuss the content of the report, the initiatives, and respond to any questions that you have along those lines.

Before I do start a description of the four initiatives, I would like an opportunity to put the report into the proper perspective and tell you what the objectives of the study are.

As you mentioned in your statement, the space program right now is facing a real dilemma. It's got to respond to realities uncovered with the *Challenger* accident. It's also got to respond to the great visions put forward by the National Commission on Space, the Paine Commission. I think it's very important that NASA respond aggressively to both of those challenges. We can't afford to neglect either, the reality of today's space program or the visions for the future space program.

The *Challenger* accident threw our space program into a very stark light. I think it called America leadership in space into question and it made the direction of the space program and perhaps the whole future of the space program a topic of public debate, public concern, concern among this committee, the entire Congress, and the administration. And it's in response to that debate and the debate on the future of the program that Dr. Fletcher asked me to come to Washington and help take part in this study on potential NASA goals.

As we have been going through this in the last several months, there have been two fundamental views that have come out from the people that we've talked to. There are many people who believe that NASA should adopt a major visionary goal. They argue that this would galvanize support for the space program, that it would focus NASA programs, it would give us a framework for our decisions, and it would help generate some excitement for the space program. And I agree with that.

There are also many others who believe that NASA's plate is already full, maybe overfull, for the mid-1990s, that the country is going to be struggling to operate the Space Shuttle in the way we hope to, and also struggling to assemble and operate the Space Station in the way that we hope to. They're not sure that NASA can handle another program on top of those two in the mid-1990s.

Now, both of these views, really rather inconsistent views, you might think reflect concern over the current state of the space program, but I don't think that either really casts it in the right light. A single goal isn't a panacea for the space program. That won't automatically solve the problems that we've got today. But, on the other hand, if there aren't clearly understood and clearly articulated goals for the space program, a clearly articulated strategy, an overall strategy for the space program, then there really is no focus to our program and there's no framework for us to make decisions. And there are important decisions that we need to be making on advanced technology, on advanced transportation, on how we hope the Space Station will evolve, and if we don't have an eye toward where we're going, we don't have any basis for making those decisions.

I think that makes it clear that what goals we adopt for the space program have to be consistent not only with our national priorities but they also have to be consistent with NASA capabilities. Now, NASA doesn't determine the goals of the space program, and I don't want to pretend that we do. That's something that is the subject of public debate, congressional debate, administration debate. But it is NASA's role, I think, to lead the discussion, to provide the technical inputs for such a discussion, and to make recommendations when called on to make those recommendations, and to be part of the decision-making process to determine the goals of the space program.

The questions that we tried to ask in our study were really where do we want to be near the turn of the century and what do we have to do now to get there, and it is not too early to be asking those questions. As I said, the transportation, technology and the Space Station really require that we address those questions now so we know what changes to make to our present programs.

The premise of this study was that the United States wanted to regain or retain, depending on your perspective, its leadership position in space. And the report does address leadership, what is meant by leadership, and how various programs, including these four initiatives, could retain leadership or regain leadership in various areas of space enterprise. So one thing that's very clear is that this country has to move very promptly, I think, to devise a coherent strategy that would retain leadership in those areas that we deem to be important.

I think that gives you a perspective from which to view the initiatives.

We really embarked on the definition of these four initiatives to energize a discussion of NASA's long-range goals. I would like to go on just a little bit more to tell you some of the ground rules that we used in adopting these and our approach, because I want everyone to understand we were not trying to set up a competition amongst the initiatives, our intent has never been to pick one and

throw away three. We decided to take this approach to get a good clear definition of four different initiatives that would help the discussion and bring the discussion to your committee, to the public, so that we can all start deciding where we want the civil space program to be going.

I guess the first ground rule we adopted was that these are bold, ambitious initiatives. We want to create bold, ambitious initiatives. These would be done on top of the existing program. There is no intent to replace any existing programs. For example, space telescope isn't included in the initiatives. There was no judgment made whether any of these was better or worse than space telescope. We took the current NASA plans as given and said what can we do on top of these.

The approach that we took to defining these initiatives was—well, it's actually the approach that I took. I decided that I know an awful lot about the Space Shuttle and more than I really want to know about solid rocket joints and O-rings, but I'm not an expert on mission to Earth, on planetary exploration, on lunar geoscience, or on Mars, and I didn't have enough time in ten months to become an expert in any one of those. So I did not set myself up as the advocate for any of these programs.

What we did was identify four initiatives—mission to planet Earth, robotic exploration of the solar system, an outpost on the Moon, and human exploration of Mars—and identify a task group and an advocate for each. The task group developed the technical aspects of the scenario, the advocate integrated all those, presented them to us and presented them also to NASA senior management, and essentially did all the speaking for those initiatives. We really sat back and listened. So although we were a part of the development of each initiative, we were not advocating any one of them and, in fact, thought it was much more appropriate for the line organizations within NASA, the real experts, to be the ones developing the initiatives and promoting the initiatives.

That may be my first disclaimer up here because, although I intend to describe all the initiatives, you may ask questions that get a little bit beyond my detailed knowledge—and we don't have any of the advocates here—so I would refer you to perhaps a future hearing with them if you're interested. But I think that I can address most of the questions that you'll be asking on the initiatives.

Each of these was developed between the period of about January and April. We used a workshop environment. We gathered the necessary expertise from inside NASA and, if necessary, outside NASA to put together these scenarios. I think what we have come up with are really four very solid initiative proposals.

Again, I need to emphasize that we really didn't want to set up a competition, and we still don't want to set up a competition, and I would prefer it not be viewed in that light. In fact, all of these programs are good programs and they're all things that NASA ought to be doing, and they're all things that I assume, given enough time, NASA will do.

[The prepared statement of Dr. Ride follows:]

Statement of
Dr. Sally K. Ride
Acting Assistant Administrator
Office of Exploration
National Aeronautics and Space Administration

before the

Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology

Mr. Chairman and Members of the Subcommittee:

I appreciate the invitation to participate in this hearing on possible civil space initiatives. For the past 11 months, at Dr. Fletcher's request, I have been directing an internal study related to this subject. I expect to submit my report to Dr. Fletcher in the near future. In the interim, I am happy to address your specific interest in the four initiatives we have developed during this effort.

In order to put today's discussion in proper perspective, let me begin with a word or two about our study and its objectives.

The civilian space program faces a dilemma, aspiring toward the visions of the National Commission on Space, but faced with the realities of the Rogers Commission report. I feel it is critical for NASA to respond aggressively to the challenges of both, while at the same time recognizing the necessity to maintain a balanced space program within reasonable fiscal limits.

After the Challenger accident, the United States' role as the leader of space-faring nations came into question. The capabilities, the direction, and the future of the space program became subjects of debate and concern within the general public, Congress and the Administration. The NASA Advisory Council observed "the Nation has no long-range goals established to serve in a policy context as the framework for specific programs and missions."

Clearly, without an eye toward the future, we flounder in the present. We should ask, "Where do we want to be at the turn of the century and thereafter?" and "What do we have to do now to get there?"

It is not too early to crystallize our vision of the space program in the year 2000 and beyond. Such a vision provides a framework for current and future programs: it enables us to know which technologies to pursue, which launch vehicles to develop, and which features to incorporate in our Space Station as it evolves. Without an understanding of where we are going, we cannot design a space program to get us there.

The basic premise of the study was that the U.S. leadership position in space should be retained. Leadership does not require that the United States be preeminent in all areas and disciplines of space enterprise. In fact, the broad spectrum of space activities and the increasing number of spacefaring nations make it virtually impossible for any nation to dominate in this way. Being an effective leader does mandate, however, that this country have capabilities which enable it to act independently and impressively when and where it chooses, and that its goals be capable of inspiring others--at home and abroad--to support them. This country must move promptly to devise a coherent strategy to retain leadership in those areas we deem important.

But the goals must be carefully chosen to be consistent with the national interest and consistent with NASA capabilities. It is not appropriate for NASA to set the goals of the civil space program. But NASA should lead the discussion of thosegoals, present options, and be prepared to make recommendations.

To energize a discussion of the long-range goals of the civil space program, we identified four candidate leadership initiatives. Each initiative was developed into a coherent proposal, then the implications and requirements of each were assessed. This process was not intended to culminate in a selection of one initiative and the elimination of the other three, but rather to provide four concrete examples which could catalyze and focus the discussion of the goals and objectives of the civil space program, and of the NASA efforts required to pursue them.

The initiatives selected for definition, study, and evaluation were:

MISSION TO PLANET EARTH

Mission to Planet Earth is an initiative to understand our home planet, how different forces shape and affect its environment, how that environment is changing, and how those changes might affect us. The goal of this initiative is to obtain a comprehensive scientific understanding of the entire Earth system, describing how its various components function, how they interact, and how they may be expected to evolve on all time scales.

The challenge is to develop a fundamental understanding of the Earth System, and of the consequences of changes to that system, to eventually develop the capability to predict changes that might occur--either naturally, or as a result of human activity.

EXPLORATION OF THE SOLAR SYSTEM

This initiative would build on NASA's long-standing tradition of solar system exploration and would continue the quest to understand our planetary system, its origin, and its evolution. Solar system bodies are divided into three distinct classes: the primitive bodies (comets and asteroids), the outer (gas giant) planets, and the inner (terrestrial) planets. Each class occupies a unique position in the history of the solar system, and each is the target of a major mission in this initiative. The initiative includes a comet rendezvous (the Comet Rendezvous Asteroid Flyby mission), a mission to Saturn (Cassini), and three sample return missions to Mars. The centerpiece of the initiative is the robotic exploration of Mars; the first of these three automated missions would bring a handful of the Red Planet back to Earth before the year 2000.

AN OUTPOST ON THE MOON

This initiative builds on the legacy of Apollo and envisions a new phase of lunar exploration and development--a phase leading to the first human outpost on another world. That outpost would support scientific research and exploration of the Moon's resource potential and would represent the first extraterrestrial step toward learning to live and work in the hostile environments of other worlds.

The initiative begins with robotic exploration in the 1990's and would land astronauts on the lunar surface in the year 2000. They would begin to construct an outpost that would evolve in size and capability and would be a vital, visible extension of our capabilities and our vision.

HUMAN EXPLORATION OF MARS

This initiative is committed to the exploration of Mars, the only other planet in our solar system with the potential to support human habitation. The initiative would begin with the robotic exploration of the planet, including the return of samples of Martian rocks and soil. Early in the 21st century, Americans would land on the surface of Mars; within a decade of these first piloted landings, this initiative would culminate in the establishment of an outpost on Mars.

These four initiatives span a spectrum of possibilities, and represent four very different visions of NASA's future. The content ranges from Earth observation to Mars exploration, and the objectives from scientific understanding to pioneering adventure.

Let me reemphasize, the intent of this study was not to choose one initiative and discard the other three, but rather to use the four initiatives as a basis for a discussion of NASA's long-range goals. The purpose was to develop the candidate initiatives, and present them to NASA management to: (1) evaluate the initiatives and their implications; and, (2) promote a discussion of the attributes of each initiative, or combinations there of, to determine the elements which are most important to NASA and to the United States. Approval to proceed with any initiative has neither been sought nor received at this time.

I do not think it would be good strategy, good science, or good policy for the United States to select a single program and then to pursue it single mindedly. Such a strategy could jeopardize the kind of balanced space program that is in the national interest. The Nation obviously cannot afford to pursue all four ambitious initiatives simultaneously. But the Nation cannot afford to ignore opportunies and challenges: the future of our space program lies in careful selection and dedicated pursuit of a coherent civil space strategy, and the health of our current space program lies in the determined development of technologies required to implement that strategy.

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Mr. NELSON. After you make your recommendations to Dr. Fletcher, do you expect this NASA leadership, in conjunction with the administration, to make a choice for a long-range goal?

Dr. RIDE. I don't know how the report will be received. I don't know what the intent is. I'm writing this report as a report from our task group to Dr. Fletcher. Dr. Fletcher I'm sure will take it under advisement and respond to it appropriately. I guess that's about all I can say. It's out of my hands when I put it on his desk.

Mr. NELSON. Okay. You see, I take it, in the writing of your report, a great deal of cross-pollinization and overlapping integrated with the Paine Commission, do you not?

Dr. RIDE. Yes. In fact, it might be a good idea if I went into some description of the initiatives so that you could get an idea of just what we had in mind.

Mr. NELSON. All right. Why don't you do that, and then we'll get to questions from the members.

Dr. RIDE. Okay. Because I think you're going to see that there is a lot in common with the Paine Commission report and, in fact, each of these initiatives, with the possible exception of the humans to Mars initiative, was an important part of the Paine Commission report. The Paine Commission, of course, assumed that Mars would be the ultimate goal of human exploration, but recommended that we get there via the Moon, that we extend our presence in a natural progression as they saw it.

These initiatives were very specifically chosen to cover the spectrum. We tried to cover a wide range of content and of complexity in the initiatives just to really get a good discussion going. We've got two initiatives that are basically science-oriented initiatives, and two that are initiatives that you might call exploration-oriented, although they, of course, have quite a bit of science and a lot of other things to say for them, too.

The first one that I will describe is the mission to planet Earth. The mission to planet Earth envisions that we would use our space base capabilities—polar platforms, geo-stationary platforms, Space Shuttle and Space Station—to really understand our home planet, how forces shape and affect its environment, how that environment is changing, and how those changes might, in turn, affect us.

What we want to do with this initiative is to obtain a very comprehensive scientific understanding of the Earth as a system. It's components are very interactive. We don't have a good understanding of those interactions yet. We would like to know how they function, how they interact, and how they might be expected to evolve.

Now, NASA pioneered remote sensing in the early 1960s and, partly as a result of that, scientists have come to understand within the last decade or so that the Earth really needs to be studied as a system. You can't study just the atmosphere or just the oceans or just the continents; you need to study them all together. And you can't study just one piece of the Earth; you need to study the whole planet. And that's where the perspective that you can get from space comes in, and I know you're very aware of that particular perspective. It's a unique perspective.

We think that this initiative would revolutionize our ability to characterize or—and it would be a very, very important step towards developing predictive models on the global environment.

Now, the guiding principle behind this is really to take an integrated approach to studying the Earth. And what we have done is identified a suite of platforms that we would put into orbit. Four of them would be Sun-synchronous polar orbiting platforms; two of them would be provided by the United States, one be ESA, one by Japan. You can begin to see the international character of this initiative.

The first platform we would see being launched in 1994, probably from Vandenberg, probably with a Titan IV. The last polar platform would be in place by 1997. We would also have five geostationary platforms up in geosynchronous orbit. That's the number that's required to cover the whole Earth from geosynchronous. Three of them would be provided by the United States, one by ESA, and one by Japan.

All of those platforms would be launched between 1996 and the year 2000. And our concept for those is to launch the platforms to the Space Station, do the assembly at the Space Station, because each of these requires a very large—about a 40 foot diameter antenna—which is much easier to assemble at the Space Station than to launch from Earth, and then send it kind of on a slow trip with a transfer vehicle up to geostationary orbit.

We would also include a whole series of low inclination experiments with these, including payloads that are attached to the Space Station and payloads that we carry in the Shuttle, and many of the payloads that we carried in the Shuttle would be a part of this entire system. In fact, I got to deploy one of them on my second flight. The Earth radiation budget satellite would be an important part of this. The imaging radar that's been carried on two Shuttle flights would be good examples of important Shuttle-based or station-based experiments that would be part of this whole package, tied together by a very impressive data management system that would integrate all the information and help us formulate our models.

The sort of things that we would be measuring are global cloud cover, vegetation cover, ice cover, rainfall and moisture, which we really don't have a very good handle on. In fact, if you just think about it for a minute, we know very little about the total amount of rainfall that occurs over the oceans. That affects the entire Earth's environment, or the Earth's system.

We would also be measuring ocean chlorophyll, ocean levels, deformations of the tectonic plates, and then possible of the most immediate interest to us, or at least probably the part that would get the most attention, we would be measuring atmospheric concentrations of things like ozone, methane, carbon dioxide. So this is an initiative that would enable us to understand problems like the ozone hole that we've all heard so much about, the buildup of greenhouse gases, the buildup of methane, and things that are really becoming more and more important to the public.

I have emphasized the international and also the inter-disciplinary nature of this. It would require very strong, very close international cooperation. It would also involve very close cooperation between NASA and the National Science Foundation and NOAA, because ground truth is important in this and the NOAA operational instruments are important in this also. That's something

that we're aware of and would need to work on probably right away.

I guess the bottom line of this really is that it's only from Earth orbit that we believe we can get the proper perspective to do this global study of the Earth and the global study of the interactions of the components. We know what to observe and we know how to observe it, and this is the first time in our history that we've been at that point, which makes this a very timely initiative.

The second—would you like me to just go straight through these?

Mr. NELSON. Yes, give us all four, and then I'm going to turn to the members for their comments and their questions.

Dr. RIDE. Okay.

The second initiative that I'll describe is also a science-oriented initiative. This exploration of the solar system, and we're talking here about robotic exploration of the solar system. This initiative builds on a very long-standing NASA tradition of solar system exploration, and it would continue those efforts to understand the planetary system, the origin of the planetary system, and the evolution of the planetary system and our place in it.

Now, the solar system is divided up into three basic classes of bodies—the inner or terrestrial planets, which is sort of from Mars in, the outer gas giant planets, which are Jupiter on out, and then the primitive bodies, which are the comets and the asteroids. This initiative would have one mission directed towards each of those, to really get a broad understanding of the solar system.

The first mission in this would be the comet rendezvous asteroid flyby craft, which I suspect this subcommittee is very, very familiar with. That's a mission that would, in the vision of this initiative, launch in 1993, go past an asteroid to do a good characterization of that asteroid, compositional studies, that sort of thing, then continue its journey on to rendezvous with a comet—in this case, Temple II—and fly formation with the comet, to do very close and detailed studies of the nucleus of the comet, and then as the comet became more active and approached the Sun, it would back off and do a good study of the coma and the tail.

That's something that we believe will give us some insight and some clues into the origin of the solar system, just because comets really are the most primitive bodies in the solar system that we have to study.

A second mission in this initiative is Cassini, a mission to Saturn. This kind of reflects that ambitious nature of the initiatives because the Cassini mission that was recommended by the Solar System Exploration Committee, the task force of the NASA Advisory Council, and was fairly well defined by that group. In this initiative, we have enhanced that considerably. We have assumed that there will be a heavy lift launch vehicle available, or this initiative would require a heavy lift launch vehicle, which greatly enhances the science that can be done on the Cassini mission. It allows you to carry three probes instead of one, and it really makes it a much more viable scientific mission.

I think, as one of the scientists said, it's a very long way to Saturn, so if you're going to go, you should probably do it right, and having a heavy lift launch vehicle allows you to do it right.

This would launch in 1998. It takes about six years to get to Saturn, six or seven years. Once it got there, the mission would start a three-year comprehensive study of the Saturnian system, the rings, the magnetosphere, and also a very detailed study of one of Saturn's moons, Titan, which is a very, very interesting body, as was revealed on the Voyager flights. That is the mission that would give us information on the outer solar system class of bodies, the outer planets.

The centerpiece of this mission is a Mars rover sample return. It's a mission that would also require a heavy lift launch vehicle in this initiative. It would launch for Mars in 1996, would land a soft landing on the surface of Mars, would send a very smart rover around on the surface of Mars to collect a variety of geologically interesting samples from Mars, bring them back to the ascent vehicle, and the ascent vehicle would return them to Space Station, probably to a quarantine facility on the Space Station, in 1999, and we'd have samples of Mars back here on Earth to study by the year 2000. I think that that is certainly the centerpiece, as I said, of this initiative and the one that I think would draw the most public interest.

That gives you a pretty good description, I think, of the three components of the initiative. The general idea is to adopt a broad strategy for systemmatic solar system exploration by covering each of the three important types of bodies in the solar system and doing it before about 2005. That's the culmination of the Cassini mission, is in 2005.

I think that gives you a pretty good idea of that one.

Mr. NELSON. You don't address the question of the international participation on the retrieval of the sample from Mars.

Dr. RIDE. We did not directly address that in this study, but there are studies going on at NASA now that are looking into the Mars rover sample return mission in quite a bit of detail, and one of the things that they are looking into is the feasibility of international participation and the feasibility of a joint mission with the Soviets, looking at it primarily from the technology transfer point of view—if you were going to design a mission, could you design it to avoid technology transfer. And their preliminary estimation so far is that yes, you could, if you designed it that way from the beginning, if you went into it thinking from the beginning.

Mr. NELSON. Okay.

What we will do now is we will recess and go vote, and come back. Dr. Ride will proceed with describing the remaining two initiatives, and then we'll proceed with the questions—Mr. Walker, Mr. Nagle, and Lewis and Mr. Perkins, in that order.

Can someone tell us what the vote is?

Mr. WALKER. It's on the rule.

Mr. NELSON. Okay, a vote on the rule. The committee will stand in recess.

[Whereupon, the subcommittee was in recess.]

Mr. NELSON. Dr. Ride, if you will proceed.

Dr. RIDE. Thank you.

The first two initiatives were really our science-oriented initiatives. The second two involve humans in a much more fundamental way.

The first one that I'll describe is human exploration of Mars. This is obviously a very bold initiative, a very ambitious initiative, that would begin in the 1990s with the robotic exploration of the planet. That would include programs like Mars Observer, probably an additional Mars Observer, Mars Observer II; a Mars rover sample return, all these in preparation for understanding the surface, the geo-chemical composition of Mars, to prepare our landing site to give us enough information to know where to land, what would be the interesting places to land and what are the potential pitfalls with the various areas.

Also in the 1990s we would have to put a very heavy focus on life sciences, because life sciences is one of the crucial areas that will either allow humans to go to Mars or which will prevent humans from going to Mars. And we have some very, very fundamental work that has to be done that really can't be started in full force until we get a space station up in orbit. So a very, very important part of this in the 1990s would be very intensive life sciences research.

The concept of this initiative is to spend the 1990s getting ready, building our technology, building our transportation, doing reconnaissance of Mars, and returning with samples from Mars, doing the life sciences research in preparation for the first human mission to Mars, which in this initiative we proposed a launch in roughly 2004, with the first human landing on Mars in 2005.

We went to some trouble in developing the scenarios to come up with a way to make these trips, one-year round trips, which cuts down some of the life sciences problems and some of the technology problems, and we conceived of having a series of three of these missions which would lead up to a decision in about the year 2010 of how we should establish our outpost on Mars, not whether we should establish it, but how we should establish it. So we conceived of this initiative not as a one-shot trip to Mars but as the beginning of exploration of the planet leading to the eventual settlement of humans on Mars.

Now, the initiative is a very long-range initiative, and I should emphasize that the first human missions can't take place before about 2005, and even that is stretching it quite a bit, especially with the recent delay in the space station. The Mars trip slips almost a year for year with the slip of the space station because of the importance of life sciences.

Those first three missions wouldn't be complete until 2010, so it's not until 2010 or later that you can begin to start building your outpost on the surface. So this is an initiative that requires a very significant commitment; it's a very visionary initiative and it requires a commitment over decades, at least two or three decades of intense work to be able to accomplish this initiative.

I think I have described the robotic exploration aspect of it sufficiently.

The life science work is critical, not just to understand the physiological effects of long duration space flight, of weightlessness, but it's also critical to develop the medical techniques, just the basic emergency room that you need to be carrying with you in your spacecraft, and I think you can probably appreciate the problems that could be associated with having to do an appendectomy, for

example, in a weightless environment. There's a lot of work that needs to be done on the technology, medical technologies, that again we won't be able to start in earnest until we get the phase one space station going.

This is a very intensive technology program. It's a very aggressive technology program. It's a very intensive emphasis on transportation. It requires heavy lift launch vehicles and it requires big, heavy lift launch vehicles, probably by about the year 2000 in this concept.

It's very dependent on the facilities that we develop in low Earth orbit. It's very dependent on the space station. The space station is where we would assemble the Mars vehicle, where we would send the fuel, where we would load the fuel on to the vehicle, and where we would actually launch both the cargo vehicle and the personnel vehicle off for Mars. They would launch from the space station, they would arrive at Mars in probably seven or eight months, be able to stay on the surface two to three weeks exploring the geochemical nature of the surface, and return probably in another six or seven months for a little bit over a year round trip and recover to the space station and be brought back down to Earth with the space shuttle. So it's an initiative that makes—that is dependent on the space station. That's probably a good way to put it.

Really, the bottom line of this initiative is that it's an extremely ambitious but visionary initiative that would send representatives of Earth to another planet, and a potentially habitable planet in our solar system, the only other one that we can conceive of inhabiting besides Earth. So it's an extremely exciting initiative that would clearly recapture leadership in the areas of human exploration.

The fourth initiative that we identified is an initiative that we call an outpost on the Moon. That's an initiative that builds on the legacy of Apollo and it envisions a new phase of lunar exploration and lunar developments. It's a phase that would lead to the establishment of an outpost on another world and it's an outpost that would support scientific research and also exploration of the Moon's resource potential, and it would represent really the first extraterrestrial step, if you like, towards learning how to live and work in the hostile environment of another body in the solar system.

This initiative also begins with robotic exploration in the 1990s. We would need to send a lunar polar orbiter to do some mapping of the surface to get a better understanding of the geochemistry and, in fact, it would be an important—an important job of this orbiter would be to look for water at the poles, to see if there is trapped water at the lunar poles. If there is, that has quite a bit of significance on where we would locate the outpost.

Through Apollo we learned that people can work on the surface of the Moon, and they can work very effectively, and we also laid the technical foundations for scientific and engineering tasks that would be necessary for this next phase of exploration. So we've got the technical basis for the establishment of an outpost. What this initiative is really is a sustained commitment to learn how to live and work in space. The second phase of the initiative begins in about the year 2000 with the return of astronauts to the Moon.

Again, the space station is a very, very critical part of this initiative, and we would envision a mission scenario as follows: we would expect the lunar vehicle to be launched from Earth up to the space station; it would be assembled at the space station; it would be fueled at the space station. The crew would go up—the lunar crew would go up to the space station and would get on the vehicle at the space station. It would be launched towards the Moon and the vehicle would be reusable and would stay in lunar orbit waiting for the crew to set up their habitation modules, their research facilities, whatever they happen to be bringing on that flight. They would go back up to and rerendezvous with the lunar vehicle and be taken back to the space station. The lunar vehicle would then stay at the space station available for the next trip and the crew would go back down in the space shuttle.

The period from about 2000 to 2005 was envisioned as the period where we would begin the building of an outpost, bringing with the first few flights the first few habitability modules and laboratory modules that I would think would be derivatives of the space station, lab modules, setting up the interior of those, the life support systems, the expert systems, the automation and robotics that's required that would be derivative from the space station work.

Over the first several flights, some of which would carry astronauts, some of which would just be cargo flights, leaving things on the surface of the Moon for the astronauts to come back later and assemble. We would envision a habitation area, a research facility, probably a rover to get around in, some small machinery so that we could start moving the lunar soil around and use it for shielding, and also a pilot plant to start demonstrating the feasibility of extracting oxygen from the lunar soil. In Apollo we learned that the lunar soil is extremely rich in oxygen, and one of the first things we want to do is set down a small, little plant that demonstrates that we can extract that oxygen from the lunar soil. If we can, that's very significant. We can use it not only on the Moon in the outpost for breathing and for fuel, getting back and forth from the Moon, but it could also be a source of oxygen fuel for our future exploration.

The third phase of this initiative really evolves from the second phase. It's just an expansion of the capabilities and the size of the outpost, and we're calling this phase "At home on the Moon". The capabilities would really evolve to a permanently occupied base. This initiative envisioned that in 2010. That may be a little bit early.

One of the advantages of this particular initiative is that it's very flexible. You can build your outpost as slowly or as quickly as you like. You can have it temporarily tended or permanently occupied, you know, whenever you like. It really doesn't affect the goals that you set for the outpost. You can set priorities and deal with them in turn. You don't have to have the whole outpost by 2010.

We would expect in this initiative that by 2010 the outpost would be permanently occupied. The base would have a closed-loop life support system. It would be doing front-line science research. It would have an operational lunar oxygen plant, and it would be an excellent test bed for our technology development.

At this point in 2010, the way that the initiative has been structured, the base would be able to support up to 25 or 30 astronauts who are living and working productively on the surface for months at a time.

This initiative also requires intensive work in technology starting soon, significant work in transportation, starting fairly soon, and the technology that's required for the work on the Moon is really technology that would make the outpost habitable and would make the people at the outpost productive, the people and the machines and the science instruments on the outpost productive. The transportation system would have to be one that was capable of regularly transporting people from low Earth orbit to the Moon and back. That's a good extension of the capabilities that we're trying to develop in low Earth orbit right now.

This initiative really is an initiative to explore the Moon for what it can tell us, but also what it can give us. It's got a lot to offer both as a research and a development center and as a resource itself, and that's what we would hope to accomplish in this initiative.

That gives you a capsule summary of the four initiatives. I am happy to go into any one of them in more detail, or answer any questions that you might have on the initiatives or their implications.

Mr. NELSON. Thank you, Dr. Ride. I'm really looking forward to reading the report after you've submitted it. And we know you're going back to the academic life, and we're going to look forward to taking the liberty of calling upon you from time to time to come here as a professor from Stanford. We're going to look forward in drawing on you as a resource as we continually try to offer some leadership to this visionary future that is so necessary in the space program. And so you have contributed mightily and I think that your contribution is just in the continuing stage, so we're going to look forward to this relationship.

Dr. RIDE. Well, I would appreciate that opportunity.

Mr. NELSON. I want to call on our members. We will call on Mr. Walker, then Mr. Nagle.

Mr. WALKER. Thank you, Mr. Chairman. I, too, join you in thanking Dr. Ride for the kind of presentation that she's given us today, and I also look forward to reading the report.

Given the fact that you have been able to look at this in depth and look out into the future a little bit, can you give us some idea as to how much you think we, as a society, ought to be spending on space in the next, say, decade?

Dr. RIDE. I haven't thought about it that way, in those specific terms. But one thing that's very clear from this study is that each of these initiatives is in addition to what NASA is doing. It builds on the base that we've got now. The budget that we've got now sustains this base. It doesn't build the base. And that any of these initiatives that we would choose to undertake require significant investment in technology and in transportation and on orbit facilities. And unless we start planning now for those investments, particularly the technology investments and the investments in automation and robotics, these initiatives are just going to stay in our future.

Mr. WALKER. Are the initiatives, as you looked at them, purely NASA initiatives?

Dr. RIDE. No, they're not.

Mr. WALKER. So it is a societal kind of thing that we are looking at doing?

Dr. RIDE. Absolutely. In fact, the mission to planet Earth is very explicitly an international initiative, and we would hope that NASA would exercise leadership by bringing the world to a mission to planet Earth.

Mr. WALKER. But how about involving other sectors of our society, such as the private sector, in some of these kinds of initiatives? How much thinking was done from that regard in these particular looks at the future?

Dr. RIDE. We didn't address the role of the private sector in our work in the development of these initiatives. I think that's something that definitely needs to be done, and it was just simply something that we didn't have time to do and we didn't address that.

There has been quite a bit of work on how the private sector might be involved in a lunar initiative, for example. There's been significant discussion of that. And I would expect that, not the private sector but other Government agencies, other agencies, would be involved very significantly in an initiative like mission to planet Earth. That's not solely in NASA's bailiwick.

Mr. WALKER. Sure. Well, I come back to my issue on spending, because I think it's something, of course, that this subcommittee ultimately will have to deal with, particularly as it affects the NASA budget. But if I look at the present situation, it appears to me as though we are spending about one percent of the Gross National Product right now in space. If you take the NASA budget, plus the Defense budget, plus the private sector activities, we're somewhere in the vicinity of 1 percent, around $40 billion a year.

Does it seem logical to you that in order to achieve the goals that you have set out here that we would probably have to double that?

Dr. RIDE. That would be a great start, if you could do that.

Mr. WALKER. Well, but I mean in terms of——[Laughter.]

I agree.

Mr. NELSON. Well said. [Laughter.]

Mr. NAGLE. Dr. Ride, hold out for three percent. [Laughter.]

Dr. RIDE. Good idea.

Mr. WALKER. It seems to me that if we talk in constant 1987 or 1988 terms, that there is no way that you can do all of the things that you're talking about here and probably do it at less than two percent of Gross National Product or something in the vicinity of $80 billion a year, $80 to $90 billion a year. And I say that not as a NASA, not purely as NASA, but as the total society contribution to that which we're doing. I want to follow that one step further, then.

Aren't there ways then that we could involve people from the private sector in—For instance, you mentioned the lunar. That's one that strikes me immediately as being one where private sector activities might be involved, that could bring contributions that would not necessarily be Government contributions to it. I mean, two weeks ago there were a lot of people who didn't know that their tax status would go up by selling Ollie North T-shirts. My

guess is that there are people who, if presented with the alternative that there's technological feasibility in going and having an outpost on the Moon, could all of a sudden come up with ways of making big money by selling, for instance, Moon rocks as gemstones. That is certainly something where there would be less availability than there is of diamonds today, that people make literally billions on selling them worldwide.

I guess my question is, how do we get that into the mix? As we're thinking about these kinds of things, how do we figure out how to get those resources into play in outlining these initiatives for our society?

Dr. RIDE. I think that's very important and that's something that NASA has traditionally not done real well, and I think is something that this country ought to begin considering.

We have had a couple of workshops over the last six or seven months—not workshops that I was directly involved in, but some that were NASA-sponsored workshops—trying to develop or just trying to test the waters and see if there was any industry interest in a lunar initiative. And, in fact, we were kind of surprised by what we found. There was a lot of interest.

Now, whether that interest would be—would turn into a real advantage for the space program is very difficult to say at this time. But unless you give the industry an opportunity and let them know what you're thinking and ask them for their reactions and ask them how they would help, you don't know the answer. I believe that it's important for us to begin doing that and to begin sort of drawing together our resources so that we, as a Nation, can undertake some of these initiatives and not leave it completely in NASA's court and Federal funding.

Mr. WALKER. One further thing.

To what extent did the potential availability of an aerospace plane figure into the development of some of the initiatives here?

Dr. RIDE. We did not consider the aerospace plane in these initiatives, and——

Mr. WALKER. Any particular reason why not?

Dr. RIDE. There really wasn't any reason that we didn't, but the aerospace plane doesn't seem to contribute to the four that we selected. There are lots of things that are a part of NASA's program right now, part of NASA's plans, that were not included in the initiative. Again, we didn't intend to make value judgments one way or the other against them. Astronomy and astrophysics isn't included in any of the initiatives, either, but that's not to say that that isn't excellent work that needs to be done.

The aerospace plane really doesn't seem to fit into any of the four initiatives as we oulined them right now.

Mr. WALKER. Well, potentially you could lower the cost of moving people from Earth to the space station. I mean, I agree with you, it doesn't have much potential for flying people to the Moon. But if you lowered the cost considerably by at least maybe a magnitude from Earth to the space station, it seems to me that could have a dramatic impact on some of these initiatives.

Dr. RIDE. It certainly—In fact, one of the major problems that we discovered, or one of the things we think is going to be NASA's major problem for either the lunar initiative or the Mars initiative

in the mid- to late 1990s, is transport of people to and from the space station. We just can't do it with the current shuttle fleet. We just can't get the people, the people traffic that we need.

Now, I should plead ignorance on the aerospace plane because I'm really not that familiar with its capabilities. But I believe we're not intending to have that as a transport to the space station as a way of supporting this sort of thing, that we would probably consider additional orbiters or personnel carriers inside an orbiter or some follow on to the space shuttle as a means of transporting people.

Mr. WALKER. Well, I'm probably over my time. I would agree with you; I don't think NASA is thinking of it in those terms, or some of us here that are thinking of it in those terms, however.

Thank you, Mr. Chairman.

Mr. NELSON. Mr. Nagle.

Mr. NAGLE. Mr. Chairman, other than thanking Dr. Ride for her report, which I thought was insightful and both visionary, I have no questions.

Mr. NELSON. On your talking of mining on the surface of the Moon, was helium III of particular interest to you?

Dr. RIDE. We did consider helium III. Helium III does exist on the Moon. It's something that we could mine there. And it's of interest because of its potential application in fusion, as I'm sure you're aware.

We, to be honest, considered that interesting and something to look into in the future, but it didn't seem that either fusion or the lunar initiative was far enough developed to really be thinking seriously about the possibility of using the Moon as a source of helium III, although it is a source of helium III.

Mr. NELSON. Mr. Perkins.

Mr. PERKINS. Thank you, Mr. Chairman. Doctor, it's good to see you again today.

I suppose I really don't have too many questions. I think we really discussed most of the specifics that I was interested in yesterday. But just in terms of making a couple of comments, I would again thank you for the effort that you have put into this and just perhaps say that I think the most important thing that is in the report is, again, on the second page that you gave us today, to energize a discussion of the long-range goals.

I think, since I have served on this committee, this is the first time that we have taken any sort of time to discuss why or what direction we should be going in with the space program and why we should be going in that direction with the space program.

You know, it strikes me that most of the mission that we seem to talk about here are ends unto themselves. The shuttle program was an end unto itself. The space station is being viewed as an end unto itself. Why—When we talked yesterday, you had one vision of what you were interested in terms of long-range goals, Bill had another, I had another. You know, ultimately I have viewed the space as being under the great frontier, where many is inextricably drawn, that ultimately will lead to some sort of colonization of space. And with that perspective, it allows everything else, to me, to fit in.

Now, I question whether we have any sort of perspective presently. It strikes me that we're just kind of going along on a hit-or-miss

basis, that whatever we encounter along the way we kind of almost do by accident. We had the one thing that seemed to energize people to go to the Moon. I mean, from time immemorial, people looked up at the Moon and they thought that was interesting and wanted to go to the Moon, but after that we had nothing that really seemed to energize the American public or appeal to the human spirit.

I just can't help but feel that we, as a committee, and we as a society, need to define what our interest in space is; what is our long-term goals? Is it to energize—is it to go to space, is it to colonize space, is it to go to the solar system, is it to go to the stars, or rather is it to focus more upon the quest for knowledge? Why is it important? Is it just to give us technological spinoffs that we power our society with? Why is it important?

I think that what you're talking about here is very important. Essentially, it strikes me that you're proposing getting comfortable with outer space stage, and that is the first thing that you're trying to get us to do. Let us get some time in space and, in essence, get comfortable with space.

Doctor, I suppose the real essence of my query here today is how far in the future do you think we should be looking and how much, and I know no one person can delineate goals. But how much should we be trying to delineate some ultimate—not ultimate, but something far enough off that will give us some sort of sense of perspective?

Dr. RIDE. First of all, let me agree with you wholeheartedly, that what we need in this country is an understanding of what our goals are and what our strategy for the space program is. And I also agree with you, that I don't believe we have that understanding right now.

The space shuttle and the space station shouldn't be goals in themselves. They should be the means for achieving our goals. The space shuttle is a way to get to orbit; it's what we do in orbit that's important. The space station is a place to live and work in orbit, but it's what we're doing while we're living and working there that's important. And those are the goals that we need to understand. We need to understand what we're using our space shuttle for and what we'll be using our space station for.

Now, your question of how far in the future should we be looking, I guess I don't know the answer to that. But just looking at it from a practical point of view, if we don't have a good understanding of what we want to be doing between 2000 and 2010, then we just don't know how to make good, rational, thoughtful decisions today on how we should be developing our technology and our space station.

In fact, the space station may be the best example. The space station is a facility that we'll start building in the mid-1990s. But we've just gone through quite a debate on what the space station should ultimately look like. That depends on what we want to do with it, and I think we've just come to that realization.

What we've got now is a pretty good approach, I think, where we've got a phase one space station with the understanding that we will evolve the space station based on what we want to do with it. And we need to figure out what we want to do with it. If we

decide we want to go to the Moon, the space station may look like one facility; if we decide that we want to pursue planetary, robotic planetary exploration, it may look different; if we want it to be a science center, a major science center, it would look different. We need to have that understanding before we make decisions on what the evolutionary path of the space station would be.

Just from the work that we've done over the last few months, it's quite clear that you need to be looking to at least the year 2000, and you're better off if you can look beyond that, and the best thing of all is to have a grand strategy, if you like, for not only your science aspirations but also your aspirations in human exploration, because it's only that that will give you the proper framework and the context for all the programs that we're developing today.

Mr. PERKINS. I agree, and I suppose ultimately the question to me is just bizarre, almost.

You know, it was interesting talking with you yesterday, and talking with Bill, because we were talking about some things—It's always just been my supposition that the whole idea of the space program was to ultimately be able to be free of the planet Earth and be able to evolve and go out to space, colonize space, and that was just always just almost an unstated assumption on my part. And yet, when we begin talking, no one seems to have any long-term goals in terms of what we're really going into space for.

You know, how do you explain, rationalize, to people here on Earth something that, in effect, you really don't seem to know why you're going there to begin with. I mean, technological spinoff is the easy answer, but I don't think that's the answer that powers this program. I don't think it's the answer that motivates people to go to space. I think we need to be more up front in terms of why we're going to space and what we want to do in space. It's just something that I think is a good thing to energize the discussion on.

Thank you, Doctor.

Dr. RIDE. I agree.

Mr. NELSON. May I interject right here. You were so eloquent yesterday, Chris, in our conversation by describing the exploratory nature of the human spirit as being one major reason of why we have a space program.

Mr. PERKINS. Absolutely.

Mr. NELSON. And so the natural answer to the question of why is, why not? Because that's what we are. By nature, we are explorers, adventurers. And if we ever squelch that spirit within us, then we, as a society, are turning inward and growing inward. So I couldn't help but—I could not let that moment pass to really build on your comments of yesterday.

Mrs. Morella.

Mrs. MORELLA. Thank you.

First of all, I'm so pleased that Dr. Ride is here with us today, and I must say that NASA's loss will be academia's gain. I have cited you as an example, as the first woman astronaut, as an example of the fact that little girls in kindergarten can say "I want to grow up and be an astronaut." So I'm really pleased with what you've done.

There are several questions that I had, and one had to do with the exploration of becoming more aware and familiar with the Earth. You talked about three agencies working together. You said NASA, the National Science Foundation, and NOAA.

How do you propose this come about, or have you looked beneath to see how they could work together and what the functions would be?

Dr. RIDE. That's a very good question. I think I may be about three weeks out of date on the answer to that, because I believe that's beginning to happen right now. I believe that there is a committee that has been set up that involves NASA, NOAA, NSF, and possibly others. I'm not the expert on this right now. In fact, it literally is happening as we speak. So I would be happy to get you more information that.

But I believe that the concept behind mission to planet Earth has actually got quite a bit of momentum behind it. We didn't initiate this idea by any means. There's been a comprehensive report out of the NASA Advisory Council that you may be familiar with that was submitted last summer—it's called the Bretherton Report—that details a lot of this and makes as one of its recommendations the establishment of an interagency council for the investigation of this sort of an initiative. To be honest, I don't know whether it was as a result of that recommendation or some other recommendation or just general interest from the international science community. But I believe that is taking place.

I would be happy to get the detailed information on that for you.

Mrs. MORELLA. It just seems as though the more we can get the agencies to work together, the more we're going to accomplish the ultimate goal.

Also, you stressed a great deal in one of the initiatives the concept of using the Moon, the lunar outpost, and therefore putting off the Mars exploration and expedition which is so dear to the heart of the Sagan society. We had originally thought we could get something going in 1990 and then it was 1992, in terms of the cooperative Mars expedition. What, in effect, you are saying is we would have to postpone it in terms of using the lunar outpost.

Do you want to comment on that?

Dr. RIDE. One thing that we—actually, two things that we didn't look into that bear a lot of study is exactly how the lunar initiative and a Mars initiative would fit into the same overall strategy. We took four very distinct initiatives and we developed their scenarios and we looked at them individually. The next step is to say okay, we've got four good initiatives here, but maybe they're not—none of them is a strategy. What would our strategy be?

A possible strategy for human exploration is to go straight to Mars. Another possible strategy for human exploration is to vault towards the Moon and then on to Mars. That one we didn't look into at all.

And I might—this may be a good place to make the point that one of the early recommendations of this study, a recommendation which we made to Dr. Fletcher, which he adopted, was the establishment of what we're calling an Office of Exploration. Because as we were going through this, we discovered that there really was no home at all in NASA for studies of a lunar initiative or a Mars ini-

tiative. That work just wasn't being done, it wasn't being coordinated, it wasn't focused, and we actually had to go to a fair amount of trouble to find the people and take them from other jobs, other things they were doing, and put them together in a task force to work on this. We recommended that those studies really should have a home, and he has since established an Office of Exploration whose job it will be to carry on these studies.

One of the first things that they're going to be looking at is, in addition to refining and developing the two initiatives that you've heard about today, start looking at trade studies and what would it mean to Mars exploration if we were to go develop a lunar outpost first and when, in the development of that outpost, would it make sense to then go on to Mars. That sort of thing we didn't look at. We recognized the need to look at it and we recommended that the Office of Exploration continue those studies, and they intend to do that.

The other thing that we did not look at in this initiative is the potential for a joint U.S.-Soviet trip to Mars. And to be honest, we just kind of decided that was above our pay grade and that, if that was going to be, that someone would tell us, and then we would start studying it. It seemed much easier to consider a U.S. initiative in that regard and just address the technical issues. So we made the decision not to consider that as one of the initiatives.

Mrs. MORELLA. Speaking of the U.S.-Soviet possibility of doing it cooperatively, I read someplace that there is supposedly going to be a U.S.-Soviet kind of biosatellite mission, but it almost seems from what I've read that it really is a Soviet initiative and that we're not certain how we get involved in it.

Are you aware—I'm sure you're aware of it. Maybe you would like to comment on that.

Dr. RIDE. I am aware of it. I'm not an expert on it, but I know that the Soviets have had an active biosat program for some number of years—I don't know the details. They've been doing life sciences experiments on their—on this biosat program, launched from expendibles usually. And my understanding is—and it's just my understanding that may be subject to correction—that as a result of the bilateral agreement that we recently signed with the Soviets, that we are now going to be participating with them in some way in their biosat program. That may be more than I really know about it.

Mrs. MORELLA. Do we get too up tight about the Soviets seeming to take the lead in the space area, or is it legitimate that we get anxious and feel that we may be wasting time by not moving ahead?

That's a general question.

Dr. RIDE. Let me not address whether we should be anxious about whether they're ahead or not, but there are very clearly areas where they are ahead of us, where they do have much more experience than we do. They've got more capabilities than we do. They've got a demonstrated launch capacity that is well above ours. Their technology is recognized to be not nearly as good as ours, but in their very evolutionary way, they have built up a series of very, very impressive capabilities. They've got a space station in orbit right now and two cosmonauts have been in it for sev-

eral months—in fact, I think they had a launch scheduled today—where they were going to launch a visiting crew that included a Syrian astronaut, cosmonaut.

They intend to leave that crew up probably for another several months. We haven't had a crew in orbit for longer than a couple of weeks, since 1974. They've had several crews up in orbit for increasingly long periods of time, and there's—no one questions that they have the lead in number of crew hours in space. They're developing just what Mr. Perkins referred to earlier, as a comfort factor in space. They know how to get to space; they know how to live in space; and they've been doing it for many years.

Mrs. MORELLA. Should we be concerned that they might reach the point where they don't look to us for help, assistance, in that area?

Dr. RIDE. I don't really think that they do look to us for assistance in most areas of their space program. In fact, I wouldn't put it that way at all. They're very eager to—and they've made it very clear—that they're very eager to cooperate with us on robotic Mars exploration. They've got three missions planned for 1988, 1992 and 1994, and they've announced an intent for a sample return mission in the late 1990s, and they would like very much to coordinate those first three missions with our Mars Observer mission, to exchange data and possibly coordinate experiments. So they're eager in certain areas to cooperate.

I don't think that they beleive they need our assistance at all, though, in their general space program, particularly their launch vehicles or their space station. They've got, just as of a month or so ago, a very capable heavy lift launch vehicle, that we don't have anything that comes close to that right now and won't for several years.

Mrs. MORELLA. Thank you.

How are you going to stay involved with the space program?

Dr. RIDE. At Mr. Nelson's invitation, I guess.

Mrs. MORELLA. Thank you.

Thank you, Mr. Chairman.

Mr. NELSON. Mr. Skaggs.

Mr. SKAGGS. Thank you, Mr. Chairman.

Thank you, Dr. Ride, for your thoughts this morning and afternoon. I had just one area I would like to ask you to comment on, in general.

You were quoted in a recent interview, I think, as identifying the mission to planet Earth initiative as perhaps the most important of the four. I wasn't sure what you were using as your criteria of importance there and wondered if you could expand on that a little bit.

Dr. RIDE. This is a purely personal opinion. But I believe that the mission to planet Earth is a very important initiative because it's very responsive to what may be a time-critical need. It's an aspect of the space program that actually does pay very close attention to our own world. It's something that could give us answers and help us in the very near future, the next decade or two decades, to understand our own planet, to understand how we might be influencing that planet, and to understand how those changes, either the ones that we're inducing or just naturally-induced changes, could

be affecting our life on the planet. And that's something that's clearly important for us to know. And it's also clear that over the last not too many years we have been effecting changes in the environment, and it's incumbent upon us to understand them.

Mr. SKAGGS. I agree with you. It seems to me, while putting it in survival terms may be a little bit overly dramatic, it is certainly a very potent set of concerns that this would address and one that, while less adventurous than some of the other initiatives, I would think could be put together in a way that appeals very directly to the growing sense that we all have of the interdependence of Earth systems and how do we really grasp that and plan for it and not affect it adversely. I would think this could be marketed, if you will, very well.

I wonder if you got into exploring, not just defining and formulating the initiatives, but what you do as next steps?

Dr. RIDE. We haven't gotten into that yet, but I share your feeling that this is something that could have broad public appeal and that could be "marketed" well, if you like. We have not—we haven't gotten into that yet.

I guess I don't know what plans we may or may not have to investigate that further.

Mr. SKAGGS. It would seem also to have, based on your preliminary outline anyway, of the best chance of international cooperation of some cost sharing and, as it is outlined, probably the least total cost of the four initiatives.

Have you put any numbers to these in that sense?

Dr. RIDE. We don't have any numbers to them. We have done sort of a level of complexity, level of resources type estimate, mostly in comparing the initiatives, not in any absolute terms at all, and not attaching any dollar figures to them, because—particularly the lunar and Mars initiatives were so far down on the curve of understanding of those initiatives, there just simply isn't enough defintion to do anything like that.

But you're right. The Earth initiative is certainly something that's well within our capabilities. We know how to launch polar platforms; we know how to put things into geostationary orbit. We are intending to evolve the capabilities on the space station that would support this. So it's something that would make good use of our existing capabilities and it's something that we understand how to do.

Mr. SKAGGS. Thank you, Mr. Chairman.

Thank you, Dr. Ride.

Mr. NELSON. Before I recognize Mr. Konnyu, let me just say that, in an aside conversation with Mr. Walker here, we were just discussing about how exciting this is and visionary.

It's interesting to note that of the three—three of the four initiatives—that it builds on the existing experience that we've already had. Mission to Earth, right there is a LandSat picture of Washington, D.C. The robotic exploration of the solar system, well, there it is right here on the walls. The outpost on the Moon, there's the beginning of it right there.

And I think in large part that's why, as a politician sensing the need for us to have a bold stroke and a major goal, that's why I would come down on the side of human exploration of Mars as

something that would give us that bold stroke, that visionary goal, while at the same time doing all of these initiatives of building on what we have already accomplished.

Mr. Walker, let's have some of your comments.

Mr. WALKER. I think Mr. Konnyu was also——

Mr. KONNYU. No, that's all right. I'll wait my turn and let my senior boys play. [Laughter.]

Mr. WALKER. The other aspect of that is, however, that in all of the things that we have here, we also—we are talking in visionary terms, and it is visionary to talk in these terms. But they are all things that we already know how to do—to some extent. Human exploration of Mars is, in fact, something which obviously requires bold new technology we haven't done, but right over there sits the Viking sitting on the surface of Mars. We have gotten there; we've landed something on Mars. And so for all the vision that's included in what we're talking about here, look around this room and we've done it. There's the Moon base, there's LandSat shooting back to Earth; there's Saturn and Jupiter and so on shot from vehicles that went by them. I mean, in the 1960s and 1970s we did all these things. And to suggest that we can't do them now just doesn't make any sense.

I was interested in a statement that Dr. Ride has in her prepared text here. She says it is not appropriate for NASA to set goals of the civilian space program. That's absolutely right. That's our job. That's—You know, NASA can't do that job. We've got to set the goals, and NASA then can give us the technology and everything to meet those goals. But we, in consultation with the presidency, we're going to have to do that. And we haven't done it. We haven't set those kinds of goals. We haven't had presidents who have set those kind of goals. We, as a Congress, haven't been a part of setting those kinds of goals. And as a result, what we have done is standing still, and we look around the room here, we've already done the things that are the visionary things for the future.

Mr. NELSON. For the major stroke, the bold stroke of the future, it takes the one person elected by the entire nation. It takes the President, as it took President Kennedy, after we had only sent Alan Sheppard up in a suborbit, within three weeks of that successful mission, to say that we were going to do what man could only imagine then, and that was we were going to the surface of the Moon and return safely within a nine-year period.

We did it. We did it because of the boldness and the imagination of a President, supported by a Congress, and that's what it's going to take again.

Mr. WALKER. But this President committed us to a space station, and we still can't get our act together enough to know whether or not that's ever going to reach fruition or not. And so, you know, it does, in fact, involve our active cooperation in setting those goals and making it a united American goal.

The point with the Moon was it became a united American goal and we have to be a part of that. It has to be more than simply the President.

Mr. NELSON. Well, let's us go to the White House and have a little prayer session down there. [Laughter.]

Mr. Konnyu.

Mr. KONNYU. All right. From the White House to Sally Ride.

First of all, Dr. Ride, I want to thank you for coming here and for this presentation. I think it's very important for America's future that NASA takes this kind of direction and that you have created this kind of what I redefine as realistic vision. I think it's very important to America.

Of course, your past history has been very important to my family. Through your dad, Dr. Ride, I have been able to get an autographed picture of you, and I have three college graduate daughters who are in business and who want to take advantage of America's opportunities and your successes gave them, in part, reassurance that they can make it in this world. So you've been a very important example not only to my family but obviously in many American families, especially families of women who aspire to create successes in this country. So I want to compliment you on your life and your leadership in America.

Dr. RIDE. Thank you.

Mr. KONNYU. With respect to the specifics, this realistic vision, of course, costs money. My colleague from Pennsylvania, Mr. Walker, discussed that in part. As part of how to fund these missions, I hear an absence of the defense-related capabilities of the United States and what we need to meet in the future as part of this planning process. Now, that's characteristic of NASA and I understand it.

Yesterday in an article I was reading about the mirror space station that the Soviets have, where they have tracked through laser capability missle warheads through space, so they're justifying the expenses of mirroring, in part, by the defense-related capability that it has and lends to the Soviet Union.

Have you gave any parallel or corollary thoughts about—in financing these four missions, how DOD's mission could be intertwined and thereby lessening the cost burden on the Government as it relates to the pure science research of it?

Dr. RIDE. No, we haven't given any thought to that. And you're absolutely right, that the Soviet space program is an integrated civil and military program. They really don't draw distinctions. I'm not familiar with the article that you cited. But it's well known that the military side of their space program is a very important side and that it's really integrated with the civilian space program. So that on any one of their space stations, they may have a combination of military and civil experiments or payloads.

We don't—we don't do things that way. We've very specifically got a civilian space agency and a Department of Defense space capability, and although the civilian side of the space agency—or the civilian space agency, because we develop national resources and national assets, we fly Department of Defense payloads when asked. Really, that is the extent of the intertwining.

I think it's very appropriate that we keep those two separate and that we have a strong and very visible civil space program and that we have a Department of Defense space program that can carry out the national security interests of the country.

Mr. KONNYU. So, therefore, the cost sharing is—and I was impressed with the realism of your vision as displayed in your four

points—the cost sharing piece of it is not there as relates to DOD in any sense at all?

Dr. RIDE. It is not—No, it's not.

Mr. KONNYU. So then Mr. Walker is essentially correct, that we're going to have to have some significantly larger level of expenditures in terms of a greater share of GNP, future GNP?

Dr. RIDE. I guess I'm not sure—Well, first of all, I'm not qualified to answer, you know, exactly what sort of increases would be needed. I'm not sure I would put it at significantly, and it depends on which of the initiatives or which combinations of the initiatives, what strategy you intend to pursue. You certainly need an increase for anything that you would do on top of the current program in the future. You know, going to Mars is one answer; doing robotic planatary exploration is another answer. And those two answers are very different, I am sure.

Mr. KONNYU. Thank you very much.

Mr. NELSON. Mr. Torricelli.

Mr. TORRICELLI. Thank you, Mr. Chairman.

Dr. Ride, if, in fact, this Government were to accept that the first option for a next American goal in space were to return to the Moon, wouldn't that be, in effect, greatly increasing the probabilities that the first man to walk on the face of Mars is going to be a Soviet?

Dr. RIDE. Well, that's a good question, and I don't think we know the answer. There are two ways to look at—Well, first let me just tell you what our perceptions are of the Soviet program.

They are undertaking a very ambitious program of robotic exploration of Mars in the late 1980s and through the decade of the '90s. I mentioned they'll be sending three probes between now and 1994 and that they hope to have a sample return mission in the late 1990s.

They don't talk about sending cosmonauts to Mars. They don't have the capability to do it any sooner, I don't believe, than we looked at in this initiative here. It's not going to happen before the turn of the century, certainly, and it's not something that they're espousing as one of their specific goals, okay. That's enough trying to read the Soviet space program.

Now, your question as to whether, if we head towards the Moon, we are giving the Soviets Mars is kind of an interesting question. Maybe we are and maybe we're not. If we decide to go to Mars by way of the Moon, we will most likely delay our getting there. It's possible that we could still get there earlier than they would. It's also possible that we might just decide to go to Mars, which is really the ultimate in exploration we can conceive right now with the Soviets.

If we declared tomorrow that we were going to go to Mars, the Soviet space program might very well decide to build an outpost on the Moon. Maybe they would elect to enter a race for Mars; maybe they would try to convince us that we should all go together to Mars, or maybe they would decide we would just—you know, we wanted Mars, so they'll go establish their outpost on the Moon.

Mr. TORRICELLI. In conversations of members of this committee with Soviet space officials during our visit to Moscow, I guess, a year and a half ago, it appeared, based on the comments they're

sharing with us, that there was an intent interest on travel to Mars, that they did not consider the technological problems to be terribly formidable—they did tell us what they did think were major problems with it—and I saw no indication—other members may have—that they considered a base on the Moon in any way a part of their thinking of an interim step.

Dr. RIDE. Uh-huh, and that's consistent with what we've seen of their program. If you think about it from their perspective right now, rushing to—Well, I go back again to what Mr. Perkins mentioned earlier and what I think is a very important feature of their space program. They move very slowly; they build their capabilities very slowly, very gradually, very evolutionary program. They get very comfortable with whatever they're doing, and then they build on that to do something else.

Right now they have built a very comfortable capability in low Earth orbit. They're starting to build comfort in having astronauts up for many, many months at a time. They're still quite a ways from having astronauts, or cosmonauts in their case, up for as long as it would take to get to and from Mars. I think the assessment that it doesn't take much advance technology to get to Mars just probably ought to be looked at again.

Mr. TORRICELLI. What they're sharing with us is the technological difficulty they found was the keeping of cosmonauts in space for that period of time, sustaining life, not the technology of having the probe arrive or land or return, so I'm not sure that's terribly different than what you're saying.

If this country—let's say a President, in 1988, who has the vision to set some goals and learns not only to make good speeches about space but also fund them, challenge us, and provide a little leadership, and what I would term the lost years of Ronald Reagan end—which is how I would characterize his leadership in the space program—and a goal is set to place an American on Mars at the turn of the century, with a real commitment of national resources, is that technologically feasible?

Dr. RIDE. I don't think we can do it by the turn of the century.

Mr. TORRICELLI. Even with sufficient resources and presidential leadership, you don't think the technology could be found?

Dr. RIDE. I think that the problem is life sciences and our understanding of life sciences—well, actually there are more problems than that to do it by the year 2000.

I give you just an example of what we—the scenario that we looked at, which attempted to minimize both the round-trip time and the amount of mass that you had to get to low Earth orbit to the space station. It's a little bit of a trade-off because in minimizing the time you increase the mass that you have to take to low Earth orbit. So what we tried to do was a trade off.

What we found for this scenario was that, assuming technological breakthroughs in aerobraking and cryogenic propellant storage, assuming those—double the numbers if you don't give me aerobraking—it takes 14 to 15 launches of a 200,000 pound heavy lift launch vehicle just to get the propellant and the crew—not the crew—the propellant and the vehicles up into low Earth orbit at the space station where you then assemble them. You know, we don't have that heavy lift launch vehicle now. I mean, it doesn't

exist. Even if we went with a heavy lift launch vehicle that we could have in the moderately near future, a shuttle-derived heavy lift launch vehicle, that would have an intermediate launch capacity, we can't have that before probably 1992 or 1993. A brand new heavy lift launch vehicle will take some time to develop. If it's got to be 200,000 pounds, you know, maybe we can have it ready by the late 1990s.

But it's a big job to launch that 14 or 15 times in the space of maybe a year, accumulate all that stuff at the space station—which we don't have yet and won't have until 1995 or 1996—and then put all the pieces together, check them out, and send a crew on its way to Mars, it's a huge task.

Mr. TORRICELLI. Nobody's suggesting it isn't a huge task. I'm just suggesting that it's appearing like such a large that nobody seems to be prepared to set times or commit the resources or to provide the national vision that it's going to take place, but just as certainly as we've described other aspects of the Soviet space policy, I'm convinced, from my conversations with their scientists—they may not be issuing press releases—but there is a real national commitment for these goals.

Dr. RIDE. That may very well be, and I agree that this country can do absolutely amazing things when it puts its mind to it, and when the commitment over a long period of time is available. It's my opinion that, even with that commitment, we couldn't get somebody to Mars by the turn of the century.

My mother called me from Los Angeles about three weeks ago and said she had just read in the LA Times that I was advocating a mission to Mars and that I said we could do it by the turn of the century. I said no, call the paper and tell them we can't do that. Because I don't believe—and I don't think that there are many people in the country who believe that we could do it by then. In fact, the studies that we did, just to make it by 2005 with the advances in technology that we assumed to be available—I mentioned aerobraking. If you don't have aerobraking, that's not 15 heavy lift launch vehicles; it's 30 heavy lift launch vehicles that have to go to a space station.

Mr. TORRICELLI. Let me ask you about the other contributions to the capability, then.

The concept of us and the Soviets having a soil return mission from Mars, independent of the knowledge to be gained from doing so, how would you quantify how vital that is as a contribution of the ultimate goal of a manned mission to Mars? Is it a critical interim step or simply an advisable and helpful interim step?

Dr. RIDE. That's a subject of debate right now. There are some people who passionately believe that it's a critical interim step; there are some people who believe that if you had enough other robotic probes earlier, like possibly several Mars Observers or surface—just landers—that you could get the information that you needed and do a good site selection and certification and understand that atmosphere.

Mr. TORRICELLI. Without the drama, expense and time of the return?

Dr. RIDE. There's one camp that thinks that that might be a possibility. There's a larger camp that thinks it is a necessary precur-

sor to human exploration. A subset of that camp believes that, because they believe that when we send people to Mars, there's the inevitable chance of contamination either of the planet or of our atmosphere on the return, so that they believe—again, this is a subset of people—believe that it's very important to get a pristine sample of Mars and get it back and understand it, do an analysis on it in our space station quarantine lab. So there would be a strong argument from that segment of people.

Mr. TORRICELLI. If your instincts are to be followed and it is a real contribution to have a return to the Moon before the Mars mission—and it would have to be justified in my mind that it makes a real and critical difference in the development of the technologies to go to Mars—I wonder if you could share with us a couple of thoughts on one or two items of real understanding or technology that would be contributed. Having now succeeded in returning to the Moon and establish a base, how are we now the better for it on a Mars mission?

Dr. RIDE. There are a couple of ways. And first let me say that I don't want to argue that the best way to go to Mars is by way of the Moon. I don't think we know that yet, and I also would fall back again to the statement that—I shouldn't be determining goals for the space program. NASA shouldn't——

Mr. TORRICELLI. Now, if you were arguing that, how would you justify the mission based on that logic?

Dr. RIDE. Based on, as a technology test bed for going to Mars?

Mr. TORRICELLI. A test bed or development tool, yes.

Dr. RIDE. There are several technologies that we know now that we will need to get to Mars that we will also need for the lunar outpost. In many cases the technologies for the lunar outpost are maybe first steps towards the ultimate technologies required for a Mars mission, Mars outpost.

Mr. TORRICELLI. And that they're easier to achieve because they've been used to Mars, to the Moon?

Dr. RIDE. Yes. And I can give you a couple of examples. In fact, one of them, I'll just use the aerobraking example.

The lunar mission would use aerobraking on return from the Moon to Earth, aerobraking in the Earth's atmosphere, of course—the Moon doesn't have an atmosphere—to slow down and recover at the space station. That's low energy aerobraking. We don't know how to do it yet. We haven't done those tests. That's an important first technology that we would have to be pursuing. But the first step to understanding the low energy aerobraking, or the first step to understanding the aerobraking that would be required coming back from Mars, which is extremely high energy aerobraking, is to understand low energy aerobraking.

Now, we can do that from experiments in orbit. That's not to say that we have to go to the Moon to get this aerobraking experience. But the aerobraking experience that we would gain in the lunar missions would help build the understanding of aerobraking as a technology for high energy interplanetary return. That's one example.

But again, you know, I want to emphasize we don't have to go to the Moon to get that understanding, but the technology that would be developed is a first step towards that for Mars.

Another example might be cryogenic propellant storage and transfer. That's an extremely important and difficult problem going to Mars, because you've got to be able to store cryogenics for at least a year-and-a-half, probably longer, just because you've got to spend a year getting them up to the space station. So once you've got them there, they've got to stay there and not boil off while you're waiting to fuel your Mars vehicle and while you're sending your Mars vehicle on the way to Mars. It's got to not boil off the fuel that will be needed for the return.

We don't have that storage technology yet. That's something we would need to start developing very soon. It's not nearly as severe a problem for the lunar missions. You still need the cryogenics, you need to get them to low Earth orbit, you need to store them; you don't need to store them in quantity or for—in as much quantity or for nearly as long as you do for Mars. So a first step in cryo-propellant storage and fuel transfer, you would gain a lot of experience and a lot of understanding in the lunar program that could be applied to Mars.

Now, again, we can develop all that technology in low Earth orbit and just try to——

Mr. TORRICELLI. Yeah, I understand your point.

Dr. RIDE [continuing]. Big tanks and leaving them up there for a long period of time. But this—you know, it would provide stepping stones to certain technologies.

Mr. TORRICELLI. Finally, let me ask you, the dispute that has taken place with regard to the Pathfinder funding and the failure of the administration to give support for basic research goals, if that were to continue another year or two, are we jeopardizing some of the goals that you studied in terms of Mars and the Moon? Even the modest dates that have been vaguely outlined here, have they been placed in any jeopardy?

Dr. RIDE. Yes. Technology development, it's, I think, pretty widely accepted that technology development is the first thing you need to start on when you start a program, and that you have to start your technology development between five and seven years before you hope to start using that technology—not just using the technology, but designing things around that technology. Technology is something that, unfortunately, you can't predict. Maybe it won't work out, maybe it will. You can't establish your designs and start spending money on a Mars vehicle, for example, until you're sure that aerobraking technology is going to be acceptable for that voyage.

We need to be starting the technology development at a serious pace within the next year or two to support both the lunar and the Mars initiatives as they were defined. In fact, both of them assumed that we would be starting technology now—you know, in FY '88 technology. We allowed that in the ambitious development of these initiatives. Again, this is—you know, we didn't necessarily have an eye towards realism in that area when we did that. We said go out and design us your ambitious initiatives and we'll allow you to start your technology development this year.

Putting off the technology development puts off the initiatives. Putting off the life sciences work, putting off the space station,

puts off a Mars initiative. And there's no way to get around those two facts.

Mr. TORRICELLI. Let me, Dr. Ride, conclude then in saying, as you leave the program for the academic life, there's a role obviously that you can play with some of these problems—some of us can't—and that you have an enormous, nonpartisan credibility with regard to the program, to remind the American people I think of a few facts that they don't know; that there is not a broad and deep national consensus for America's space exploration; American leadership is not simply being jeopardized, it is being lost. We have, for the most part, lost a decade. It is time that we cannot reclaim. And that there is a real difference between using the public's sentiments in favor of the space program in a speech and challenging them to make sacrifices, pay the cost, and meet some goals. You can play that role, because nobody else is. At some point in another decade, the American people are going to look back at the 1980s and say just how did we lose our leadership in space and the resulting economic, scientific and military benefits that would have accrued. It was lost and nobody told us. Nobody is telling them, because they're listening to the speeches rather than reading the numbers. So that's my suggestion for your future.

Thanks for the answers to my questions.

Mr. NELSON. Now you have your whole career outlined. [Laughter.]

Let me say that your work has been and will be enormously valuable, building on the report from the National Commission on Space as we determine what our priorities are and what our goals should be. And let me underscore also what has been said here and just make it a little more vivid.

That NASA has asked for a budgetary amendment through OMB for fiscal year 1988 for an additional $55 million for this space leadership initiative. And basically you have cutlined how the initiative needs to have some action now, and that money would be provided for it.

Do you have any comment you want to make about that before we adjourn?

Dr. RIDE. NASA did submit a request for Project Pathfinder which was developed in conjunction with this work that would provide the first steps towards developing the technologies for both the lunar and the Mars initiative. We feel that it's the beginning of the technology that's truly enabling to these initiatives. We can't do the initiatives without this technology.

That was submitted as part of a budget amendment in November. and it was not included in the President's budget.

Mr. NELSON. All right. Well, therein is underscoring part of what Mr. Torricelli was talking about.

You have been exceptionally helpful to us as we deliberate on these matters, and that will be a specific item that we will be taking up.

I would—a couple of little housecleaning things here. Without objection, we will allow recording devices to be here in the committee.

I have a statement from Mr. Brown, who he would like entered in the record, without objection.

[The prepared statement of Mr. Brown follows:]

GEORGE E. BROWN, JR.

HEARING ON LONG-RANGE GOALS FOR NASA

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

JULY 22, 1987

MR. CHAIRMAN, TODAY WE WILL HEAR FROM DR. SALLY RIDE ON LONG-RANGE GOALS FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA). THE TOPIC OF TODAY'S HEARING, IN MY OPINION, IS THE MOST IMPORTANT ELEMENT OF NASA'S EFFORT TO RECOVER FROM THE DESTRUCTION OF THE SPACE SHUTTLE CHALLENGER. UNFORTUNATELY, NEITHER CONGRESS NOR THE ADMINISTRATION HAS PLACED SPACE POLICY AND GOAL-SETTING AS A PRIORITY IN THE RECOVERY EFFORT. I FEEL THE PROBLEMS OF THE AMERICAN SPACE PROGRAM HAVE BEEN COMPOUNDED BY THIS LACK OF LEADERSHIP.

I REALIZE, MR. CHAIRMAN, THAT THE SUBCOMMITTEE USUALLY TAKES THE OPPORTUNITY AT HEARINGS SUCH AS THIS TO GAZE WITH AWE INTO NASA'S CRYSTAL BALL, AND TALK IN ENCOURAGING TONES. I CONFESS THAT I HAVE DIFFICULTY SPEAKING IN POSITIVE TONES ABOUT THE FUTURE OF THE SPACE PROGRAM GIVEN THE ACTION--OR RATHER INACTION--WITHIN THE ADMINISTRATION AND CONGRESS IN SETTING COMPREHENSIVE GOALS FOR THE FUTURE OF THE SPACE PROGRAM.

DR. RIDE APPEARS BEFORE US MORE THAN 18 MONTHS AFTER THE CHALLENGER ACCIDENT, READY TO PRESENT A SET OF GOALS THAT ARE BEING DEVELOPED INTERNALLY BY NASA. WITH ALL DUE RESPECT TO DR. RIDE AND NASA, THIS, TO ME, IS TESTIMONY TO THE LACK OF LEADERSHIP COMING FROM ADMINISTRATION ON SPACE POLICY. STRONG AND DECISIVE GOALS SHOULD HAVE BEEN SET MONTHS AGO. YET, EVEN TODAY THERE IS NO CERTAINTY THAT THE PRESIDENT WILL ADOPT THE RECOMMENDATIONS THAT SALLY RIDE IS PRESENTING.

AMERICA HAS DEALT ADMIRABLY WITH THE IMMEDIATE NEEDS OF BRINGING THE SPACE SHUTTLE PROGRAM BACK TO FLIGHT STATUS. WE HAVE TAKEN STEPS TO BUILD A MIXED FLEET OF EXPENDABLE LAUNCH VEHICLES FOR ASSURED ACCESS TO SPACE INTO THE 1990s. DESPITE PROBLEMS WITH THE SPACE STATION, IT IS GENERALLY AGREED THAT WE MUST MOVE AGGRESSIVELY WITH THAT PROGRAM. IN ADDITION, LEGISLATIVE STEPS APE BEING TAKEN TO ENSURE THAT THE SHUTTLE AND SPACE STATION ARE NOT ALLOWED TO CHOKE THE SPACE SCIENCE PROGRAM--ALTHOUGH GREATER STRIDES MUST BE MADE IN THIS AREA.

WE HAVE DEALT WELL WITH THE NEAR TERM FIXES IN THE SPACE PROGRAM, BUT HAVE NOT FOCUSED OUR ATTENTION ON THE LONG-RANGE GOALS THAT PROVIDE THE DIRECTION AND MOTIVATION FOR OUR NEAR-TERM ACTIVITIES. LACK OF DIRECTION, AS MUCH AS ANYTHING ELSE, CAUSED THE CHALLENGER ACCIDENT. YET RATHER THAN RESPONDING WITH STRONG LEADERSHIP AND PURPOSE, CONGRESS AND THE WHITE HOUSE ARE AGAIN PLACING LONG-RANGE GOALS AS A LOW PRIORITY. THIS ATTITUDE WILL ONLY BEGIN ANEW THE CYCLE FOR DISASTER.

LAST YEAR, THE NATIONAL COMMISSION ON SPACE ISSUED ITS FINDINGS AND RECOMMENDATIONS IN A VISIONARY DOCUMENT. FOR ALL THE INITIAL ENTHUSIASM FOR THE REPORT, ITS WORDS HAVE FALLEN ON DEAF EARS AT THE WHITE HOUSE. BECAUSE NASA AND THE ADMINISTRATION WERE TAKING LITTLE ACTION IN REPONSE TO THE PAINE COMMISSION REPORT, I FELT IT NECESSARY TO INCLUDE LANGUAGE IN THE NASA AUTHORIZATION BILL WHICH REQUIRES NASA TO REPOND TO THE REPORT.

TODAY, WE WILL HEAR FROM DR. SALLY RIDE ON HER LONG-TERM PLANNING EFFORTS, AS WELL AS ON THE NEW OFFICE FOR EXPLORATION. I AM ENCOURAGED BY THIS INITIATIVE, AND COMMEND THE ADMINISTRATOR OF NASA, DR. JAMES FLETCHER FOR HIS FORESIGHT. THE FOUR MAJOR GOALS THAT HAVE BEEN WIDELY REPORTED DEMONSTRATE TRUE VISION, AND ARE CLEARLY CONSISTENT WITH THE PAINE COMMISSION RECOMMENDATIONS. FOCUSING ON THE EARTH SYSTEMS IS THE MOST RESPONSIBLE APPLICATION OF OUR SPACE TECHNOLOGY. "MISSION TO PLANET EARTH," AS PART OF THE GLOBAL CHANGE EFFORT UNDER DISCUSSION IN OTHER SCIENCE SUBCOMMITTEES THIS WEEK, WILL LEAD TO A BETTER UNDERSTANDING OF HOW MAN INTERACTS WITH HIS ENVIRONMENT. BUT TO KNOW EARTH, WE MUST KNOW OUR SOLAR SYSTEM. A THOROUGH EXPLORATION OF OUR SOLAR SYSTEM WITH UNMANNED PROBES COULD UNLOCK THE SECRETS OF OUR ORIGINS. SETTING THE GOAL OF RETURNING TO THE MOON--AND STAYING THERE--IS AN ESSENTIAL STEP TOWARD THE LARGE SCALE DEVELOPMENT OF SPACE. THE ULTIMATE STEP FOR MANKIND WILL BE TO TRAVEL BEYOND THE EARTH-MOON SYSTEM TO EXPLORE AND SETTLE OTHER WORLDS WITHIN THE SOLAR SYSTEM. THE NEXT LOGICAL PLANET FOR MANNED EXPLORATION IS MARS.

ALTHOUGH I AM EXCITED ABOUT DR. RIDE'S EFFORT, I STILL FEEL IT APPROPRIATE TO REQUIRE NASA TO RESPOND DIRECTLY TO THE NATIONAL COMMISSION ON SPACE. THIS WILL GIVE CONGRESS A BROADER RANGE OF DOCUMENTATION TO REVIEW WHEN APPROVING SPACE GOALS, SHOULD THE ADMINISTRATION PROPOSE ANY. RESPONSE TO THE PAINE COMMISSION REPORT COULD BE ACHIEVED THROUGH THE EFFORTS OF DR. RIDE'S TASK FORCE, IN PREPARING ITS FINAL REPORT. IT WOULD BE APPROPRIATE, FOR EXAMPLE, FOR DR. RIDE TO INCLUDE THE NASA REPONSE TO THE PAINE COMMISSION REPORT IN HER STUDY.

I WOULD LIKE ALSO TO STRESS THAT NASA'S LONG-RANGE PLANNING EFFORTS AGGRESSIVELY INCORPORATE INTERNATIONAL COOPERATION. THE LONG-RANGE GOALS THAT NASA IS SUGGESTING CANNOT BE ACCOMPLISHED IN ALONE. WE MUST GO AS EQUAL PARTNERS INTO SPACE, IN BOTH UNMANNED AND MANNED EFFORTS. THE UNITED STATES IS RAPIDLY DECLINING AS THE PREEMINENT SPACEFARING NATION, AS OTHER NATIONS GROW IN THEIR CAPABILITIES. WE MUST INCREASINGLY SEEK WAYS TO COOPERATE ON SPACE PROJECTS WITH OTHER NATIONS--INCLUDING THE SOVIET UNION.

FINALLY, THE KIND OF LONG-RANGE GOALS THAT ALL OF US HAVE IN MIND WILL NOT BE ACHIEVED WITHIN THE CURRENT BUDGET LIMITATION. TO GET WHERE WE WANT TO GO IN SPACE WILL REQUIRE SERIOUS AUGMENTATION OF THE NASA BUDGET OF FIVE TO 10 PERCENT IN REAL GROWTH OVER A 10 YEAR PERIOD BEFORE LEVELING OFF. THIS AMOUNT MAY SEEM EXCESSIVE TO MANY OF MY COLLEAGUES, BUT IF WE ARER NOT

GOING TO SUFFICIENTLY SUPPORT THE SPACE PROGRAM, THE DISCUSSION WE ARE HAVING TODAY ON RETURNING TO THE MOON IS, FRANKLY, A WASTE OF TIME.

THANK YOU, MR. CHAIRMAN.

[5]

Mr. NELSON. And you are invited into our committee office here right now to meet and discuss a couple of additional items with members.

Thank you, and the hearing is adjourned.

[Whereupon, at 1:20 p.m., the subcommittee was adjourned.]

APPENDIX

LEADERSHIP

and America's Future in Space

A Report to the Administrator
By Dr. Sally K. Ride
August 1987

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NASA

National Aeronautics and
Space Administration

Washington D C
20546

Office of the Administrator

AUG 12 1987

Dr. Sally K. Ride
Special Assistant to the Administrator
National Aeronautics and
Space Administration
Washington, DC 20546

Dear Sally:

Your report, Leadership and America's Future in Space, fully meets the challenge you have set for your effort: you have contributed strongly to a process that will determine the goals and directions of the nation's civil space activities well into the next century.

I commend the principles of careful program balance and sustained national commitment you espouse. I particularly appreciate the emphases you place on the need for a very broad, very solid base of enabling technologies upon which to build any future program. The four initiatives you have chosen as possible points of focus for national leadership nicely bracket the spectrum of possibilities and should serve to energize and guide the debate on NASA's next set of technical activities aimed at turning a national vision into a programmatic reality.

I also want to note my personal—as well as NASA's official—appreciation for your contribution to our overall strategic and long-range planning, in terms both of content and process. Our processes from now on will owe much to your pathfinder work. Your "1A" group of young tigers has shown us all how much intellectual energy is available to us if properly awakened. And the new Office of Exploration is another permanent contribution to NASA in which you should take satisfaction.

You have well and truly discharged the difficult task I asked you to undertake. You have opened a bright window on the issues of leadership in space and the means to reach—and sustain—that position. It is with deep appreciation that I accept your report, Leadership and America's Future in Space.

Sincerely,

James C. Fletcher
Administrator

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PREFACE

For nearly a quarter of a century, the U.S. space program enjoyed what can appropriately be termed a "golden age." From the launch of Earth-orbiting satellites, to the visits by robotic spacecraft to Venus and Mars, to the stunning achievement of landing the first human beings on the Moon, the many successes of the space program were exciting and awe-inspiring. The United States was clearly and unquestionably the leader in space exploration, and the nation reaped all the benefits of pride, international prestige, scientific advancement, and technological progress that such leadership provides.

However, in the aftermath of the *Challenger* accident, reviews of our space program made its shortcomings starkly apparent. The United States' role as the leader of spacefaring nations came into serious question. The capabilities, the direction, and the future of the space program became subjects of public discussion and professional debate.

The U.S. civilian space program is now at a crossroads, aspiring toward the visions of the National Commission on Space but faced with the realities set forth by the Rogers Commission. NASA must respond aggressively to the challenges of both while recognizing the necessity of maintaining a balanced space program within reasonable fiscal limits.

Two fundamental, potentially inconsistent views have emerged. Many people believe that NASA should adopt a major, visionary goal. They argue that this would galvanize support, focus NASA programs, and generate excitement. Many others believe that NASA is already overcommitted in the 1990s; they argue that the space agency will be struggling to operate the Space Shuttle and build the Space Station, and could not handle another major program.

Both views reflect concern over the current status of the space program, but each deals with only one aspect of the problem. The space program needs a long-range direction; it also needs the fundamental capabilities that would enable it to move in that direction. A single goal is not a panacea—the problems facing the space program must be met head-on, not oversimplified. But if there are no goals, or if the goals are too diffuse, then there is no focus to the program and no framework for decisions.

The goals of the civilian space program must be carefully chosen to be consistent with the national interest and also to be consistent with NASA's capabilities. NASA alone cannot set these goals, but NASA must lead the discussion, present technically feasible options, and implement programs to pursue those goals which are selected.

We must ask ourselves: "Where do we want to be at the turn of the century?" and "What do we have to do now to get there?" Without an eye toward the future, we flounder in the present. It is not too early to crystallize our vision of the space program in the year 2000. A clear vision provides a framework for current and future programs: it enables us to know which technologies to pursue, which launch vehicles to develop, and which features to incorporate into our Space Station as it evolves.

Leadership in space does not require that the U.S. be preeminent in all areas of space enterprise. The widening range of space activities and the increasing number of spacefaring nations make it virtually impossible for any country to dominate in this way. It is, therefore, essential for America to move promptly to determine its priorities and to pursue a strategy which would restore and sustain its leadership in the areas deemed important.

The Rogers Commission, in its concluding thoughts, states that NASA "constitutes a national resource that plays a critical role in space exploration and development. It also provides a symbol of national pride and technological leadership. The Commission applauds NASA's spectacular achievements of the past and anticipates impressive achievements to come." Only with a clear strategy in place, and its goals for the future defined and developed, will the country be able to regain and retain leadership in space.

INTRODUCTION

In response to growing concern over the posture and long-term direction of the U.S. civilian space program, NASA Administrator Dr. James Fletcher formed a task group to define potential U.S. space initiatives, and to evaluate them in light of the current space program and the nation's desire to regain and retain space leadership. The objectives of the study were to energize a discussion of the long-range goals of the civilian space program and to begin to investigate overall strategies to direct that program to a position of leadership.

The task group identified four candidate initiatives for study and evaluation. Each builds on NASA's achievements in science and exploration, and each is a bold, aggressive proposal which would, if adopted, restore the United States to a position of leadership in a particular sphere of space activity. The four initiatives are: (1) Mission to Planet Earth, (2) Exploration of the Solar System, (3) Outpost on the Moon, and (4) Humans to Mars. All four initiatives were developed in detail, and the implications and requirements of each were assessed.

This process was not intended to culminate in the selection of one initiative and the elimination of the other three, but rather to provide four concrete examples which would catalyze and focus the discussion of the goals and objectives of the civilian space program and the efforts required to pursue them.

When this activity began, several studies relevant to NASA's long-range goals and its ability to achieve those goals were already in progress. Some of these studies were being conducted by agencies external to NASA; others were internal NASA studies. This task group became familiar with those efforts, and sponsored others in areas not already covered. Additional information on all these studies is provided at the end of this report. The interested reader is referred to the published reports for detailed recommendations.

The major milestones of all relevant studies were plotted on a timeline, shown in **Figure 1**. This proved to be a useful summary for identifying the activities and their projected completion dates. A similar overview timeline should continue to be produced and revised, since it raises awareness of existing studies and coordinates related efforts.

This is not a final report. Rather, it is a status report describing the work accomplished to date, and how this work will continue. The report discusses long-term goals of the civilian space program, current posturing required to attain these goals, and the need for a continuing process to define, refine, and assess both the goals and the strategy to achieve them.

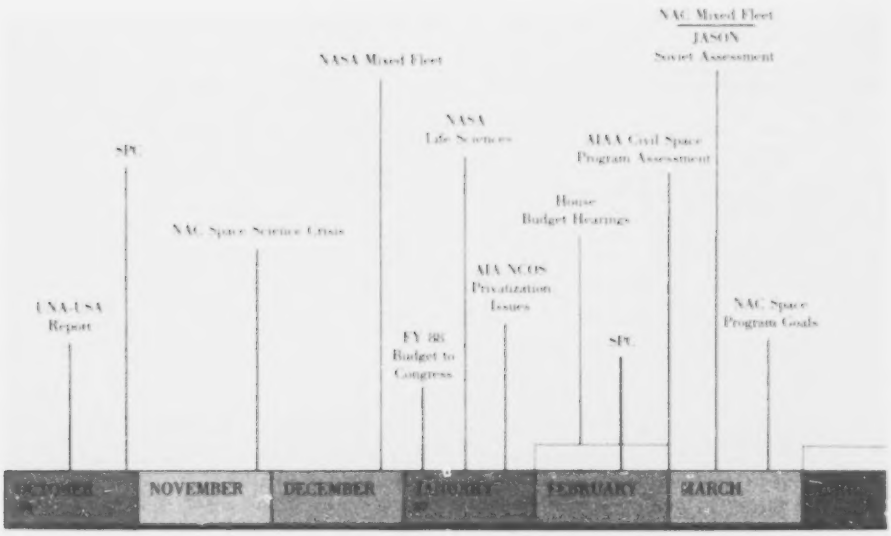
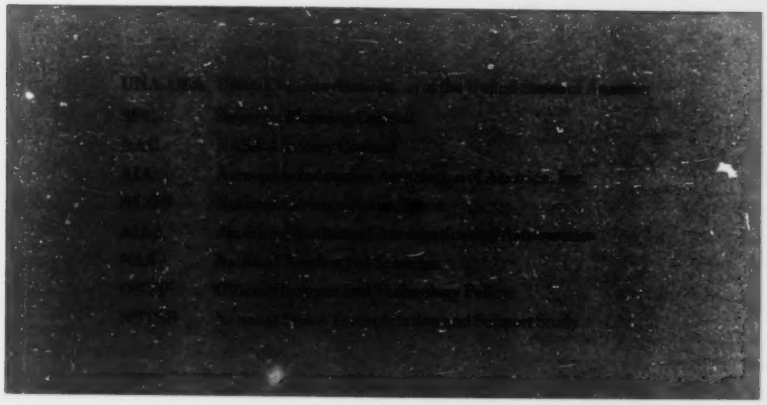
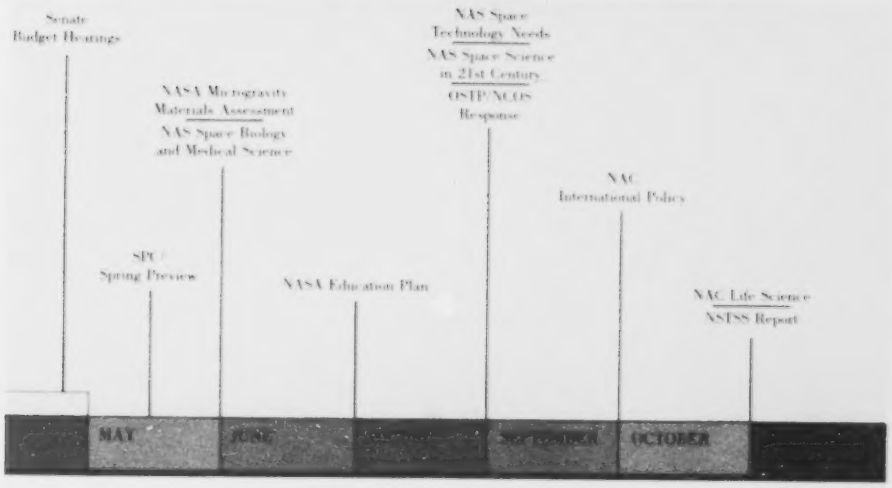


Figure 1. NASA Strategic/Long-Range Planning Activities




Senate
Budget Hearings
NASA Microgravity
Materials Assessment
NAS Space Biology
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SPC
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Technology Needs
NAS Space Science
in 21st Century
OSTP/NCOS
Response
NAC
International Policy
NAC Life Science
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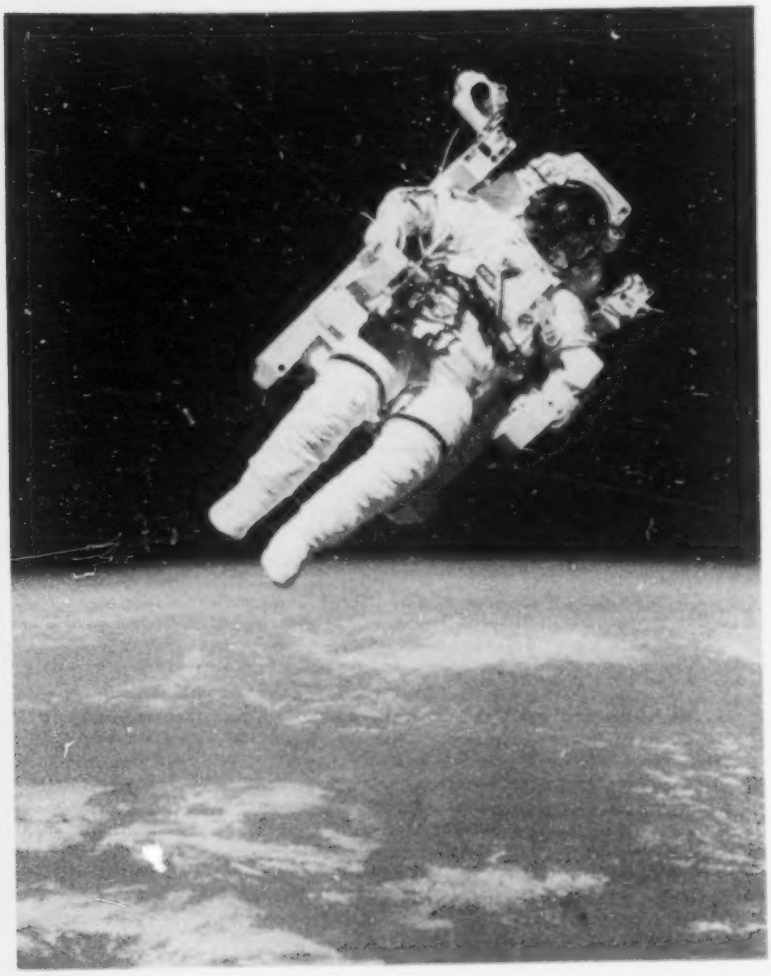

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LEADERSHIP IN SPACE

For two decades, the United States was the undisputed leader in nearly all civilian space endeavors. However, over the last decade the United States has relinquished, or is relinquishing, its leadership in certain critical areas; one such area is the exploration of Mars. With the *Mariner* and *Viking* missions in the 1960s and 1970s, this country pioneered exploration of Mars – but no American spacecraft has visited that planet since 1976. Our current plans for future exploration of Mars include only the *Mars Observer* mission, to be launched in 1992. In contrast, the Soviets have announced a program of extensive robotic exploration of the Martian surface, beginning in 1988 and extending through the 1990s.

The Soviets are now the sole long-term inhabitants of low-Earth orbit. The first, and only, U.S. space station, *Skylab*, was visited by three crews of astronauts before it was vacated in 1974; the U.S. has had no space station since. The Soviets have had eight space stations in orbit since the mid-1970s. The latest, *Mir*, was launched in 1986 and could accommodate cosmonauts and scientific experiments for nearly a decade before the U.S. Space Station can accommodate astronauts in 1995.

The United States has clearly lost leadership in these two areas, and is in danger of being surpassed in many others during the next several years.

The National Space Policy of 1982, which "establishes the basic goals of United States policy," includes the directive to "maintain United States space leadership." It further specifies that "the United States is fully committed to maintaining world leadership in space transportation," and that the civilian space program "shall be conducted ... to preserve the United States leadership in critical aspects of space science, applications, and technology."

Leadership cannot simply be proclaimed – it must be earned. As NASA evaluates its goals and objectives within the framework of the National Space Policy, the agency must first understand what is required to "maintain U.S. space leadership," since that understanding will direct the selection of national objectives.

Leadership does not require that the U.S. be preeminent in all areas and disciplines of space enterprise. In fact, the broad spectrum of space activities and the increasing number of spacefaring nations make it virtually impossible for any nation to dominate in this way. Being an effective leader does mandate, however, that this country have capabilities which enable it to act independently and impressively when and where it chooses, and that its goals be capable of inspiring others – at home and abroad – to support them. It is essential for this country to move promptly to determine its priorities and to make conscious choices to pursue a set of objectives which will restore its leadership status.

Leadership results from both the capabilities a country has acquired and the active demonstration of those capabilities; accordingly, the United States must have, and also be perceived as having, the ability to meet its goals and achieve its objectives.

A U.S. space leadership program must have two distinct attributes. First, it must contain a sound program of scientific research and technology development – a program that builds the nation's understanding of space and the space environment, and that builds its capabilities to explore and operate in that environment. The United States will not be a leader in the 21st Century if it is dependent on other countries for access to space or for the technologies required to explore the space frontier. Second, the program must incorporate visible and significant accomplishments; the United States will not be perceived as a leader unless it accomplishes feats which demonstrate prowess, inspire national pride, and engender international respect and a worldwide desire to associate with U.S. space activities.

National pride and international prestige are two natural benefits of leadership in space. National pride grows as citizens recognize their country's abilities and achievements; international prestige rises as other nations recognize those abilities and achievements.

Perhaps most significant, leadership is also a process. That process involves selecting and enunciating priorities for the civilian space program and then building and maintaining the resources required to accomplish the objectives defined within those priorities. NASA can contribute to this process by: (1) establishing a vision and goals consistent with national space interests; (2) developing and recommending objectives and programs that support those goals; (3) articulating, promoting, and defending them in the political and fiscal arenas; and (4) effectively executing approved programs.

To this end, NASA embarked last fall on a review of its goals and objectives. As NASA Administrator Dr. James Fletcher stated, "It is our intent that this process produce a blueprint to guide the United States to a position of leadership among the spacefaring nations of Earth."

The first step in this necessarily lengthy process was taken by NASA Senior Management's Strategic Planning Council when it adopted the statement in the box on the next page.

This statement reflects the belief that NASA embodies the human spirit's desire to discover, to explore, and to understand. It should be noted that the Space Shuttle and Space Station are not viewed as ends in themselves, but as the means toward achieving the broader goals of the nation's space program. Transportation and orbital facilities support and enable our efforts in science, exploration, and enterprise.

The next step in this process should be to articulate specific objectives and to identify the programs required to achieve these objectives. Of course, in some areas of study the programs have already been identified and are well under way. For example, The Hubble Space Telescope, a general-purpose astronomical observatory in space, is an element of NASA's program to increase our understanding of the universe in which we live; the redesign and requalification of the Space Shuttle's solid rocket booster joint is part of NASA's program to return the Space Shuttle to flight status. However, in other areas, such as piloted exploration, our objectives have not been clearly identified. Does this country intend to establish a lunar outpost? To send an expedition to Mars? What are NASA's major objectives for the late 20th and early 21st Centuries? The Space Shuttle and Space Station will clearly support the objectives, but what will they be supporting?

These questions cannot, of course, be answered by NASA alone. But NASA should lead the discussion, propose technically feasible options, and make thoughtful recommendations. The choice of objectives will shape, among other things, NASA's technology program, the evolution of the Space Station, and the character of Earth-to-orbit transportation.

MEETING THE CHALLENGE IN AERONAUTICS AND SPACE

NASA's vision is to be at the forefront of advancements in aeronautics, space science, and exploration. To set our course into the 21st Century and bring this vision to reality, NASA will pursue major goals which represent its aspirations in aviation and space. These goals are:

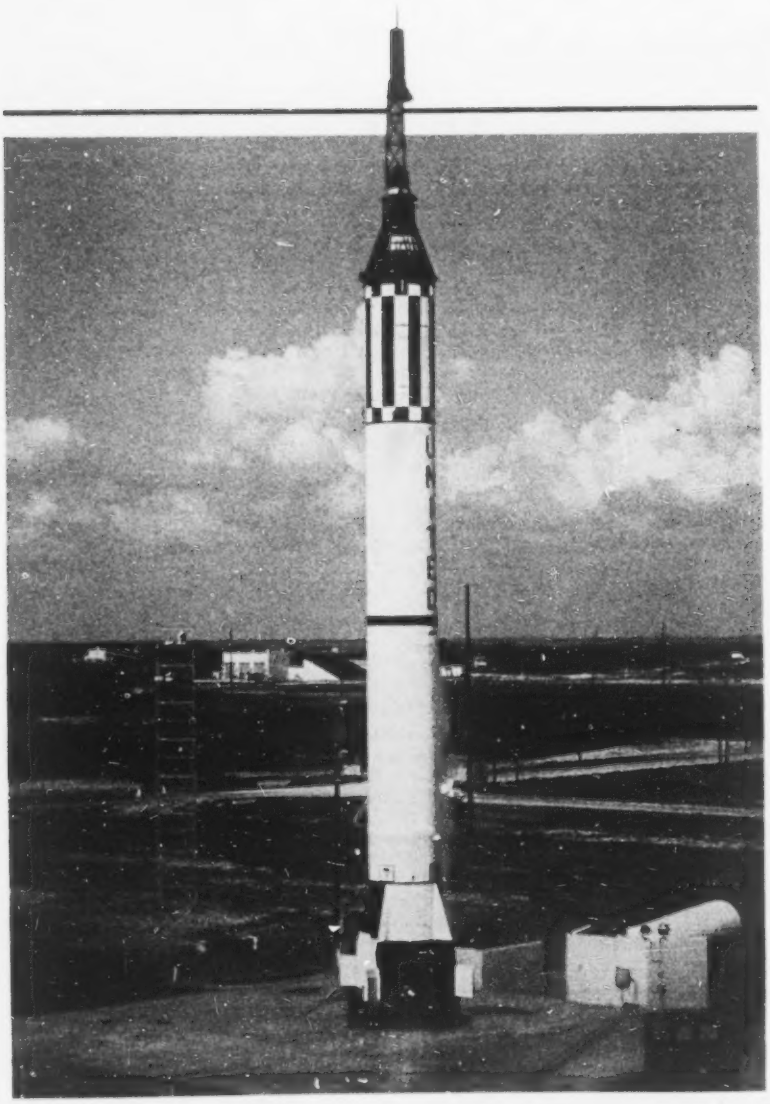
- **Advance scientific knowledge of the planet Earth, the solar system, and the universe beyond.**
- **Expand human presence beyond the Earth into the solar system.**
- **Strengthen aeronautics research and develop technology toward promoting U.S. leadership in civil and military aviation.**

Successful pursuit of these major goals requires commitment to the following supporting goals:

- Return the Space Shuttle to flight status and develop advanced space transportation capabilities.
- Develop facilities and pursue science and technology needed for the Nation's space program.

As NASA pursues these goals, we will:

- Promote domestic application of aerospace technologies to improve the quality of life on Earth and to extend human enterprise beyond Earth.
- Conduct cooperative activities with other countries when such cooperation is consistent with our national space goals.



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STRATEGIC OPTION DEVELOPMENT

The statement adopted by the Strategic Planning Council describes NASA's mission, its vision, and the scope of its activities. But the next step in the process cannot be taken in the absence of a comprehensive strategy for the civilian space program. Without a coherent formulation of the United States' intentions and priorities, there is no context in which to evaluate the relevance or the importance of any proposed initiatives.

To lay the foundation for the definition and articulation of such a strategy, NASA is currently developing a process to systematically assess the posture of our space program and to refine and assess candidate strategies to direct its future. This process, strategic option development, is still in its early stages; nevertheless, the development of the process has yielded some interesting insights into existing and potential space strategies.

The application of strategic option development to charting the future of the U.S. space program initially evolved from analogies drawn from relevant aspects of business theory. Although it is unconventional to think of space endeavors in terms of a business, many concepts from the business world are applicable and quite useful.

Leadership in business is possible at any time during a product's life cycle. When a new product is introduced (the innovator stage) there is no competition. If the product is successful, the firm becomes the market leader by default. The drawback, of course, is that innovators must accept the high cost and high risk associated with being first. The space program in the early 1960s was an innovator's market. Nearly every successful effort produced a "first," but the risks, as well as the number of failures, were very high.

The launch of America's first astronaut in space, Alan B. Shephard Jr., on the Mercury Redstone II from Cape Canaveral on May 5, 1961.

In a mature business market (the late majority stage) there exists a balance, as many firms compete for some share of the market. At this stage, it is still possible to be a market leader by carving out a particular niche of that market or by delivering the highest quality or best value. The launch vehicle market, for example, is approaching a more mature stage, and many countries will be vying for leadership in the 1990s.

A firm engaged in more than one market must develop an integrated strategy which provides the flexibility to be both an innovator in a new market and the leading competitor in a mature market; this principle should be applied to a space program as well.

The business of space has expanded considerably since the 1960s. The areas of scientific research, space technology, space exploration, and space services are still open to leadership through innovation, but some are also now open to leadership in more mature markets. In fact, national space programs must now look at four stages of space leadership: (1) the *pioneer* stage, innovation in some particular area of research, technology, or exploration; (2) the *complex second* stage, a continuation of a pioneering effort, but with broader, more complex objectives; (3) the *operational* stage, with relatively mature and routine capabilities; and (4) the *commercially viable* stage, with the potential for profit-making.

The activities of a space program can be characterized by physical regions of space: (1) deep space, (2) the outer solar system (the planets beyond the asteroid belt), (3) the inner solar system (the inner planets, the Moon, and the Sun), (4) high-Earth orbit, and (5) low-Earth orbit. Supporting technologies, such as launch capabilities and orbital facilities, are required to undertake all programs.

The complex concept of space leadership may be broken down into logical elements to form a two-dimensional matrix. The columns of the matrix are delineated by the four leadership stages outlined previously; the rows are the five physical regions of possible space activities, with a sixth row for supporting technologies and transportation. Each square of the matrix defines a particular area of possible leadership.

This matrix analysis provides a way to conceptualize alternative courses of action and can be used to describe and assess the space programs of spacefaring nations. It is possible to be a leader in a single square through any of a number of different programs. **Figure 2** illustrates several programs which, if undertaken in the 1990s, would result in leadership in one area of space endeavor. For example, a country could be a leader in the highlighted area of a complex second effort in the inner solar system by successfully establishing a lunar outpost or by sending sophisticated rovers to other worlds.

Not all the squares will be accessible in the next decades. Technology has not progressed to the point that any nation is able to contemplate, for example, commercial prospects in the outer solar system. This figure does not represent a particular strategy; rather, it represents a collection of potential programs.

Being a leader in one area no longer results in overall space leadership. In the early 1960s, the United States and the Soviet Union were the only competitors, and only the cells in the lower left corner of the matrix were accessible. As technology advanced and nations gained experience in space, the opportunities began to expand. In the 1960s, the U.S. learned to send satellites to geosynchronous orbit, scientific experiments to low-Earth orbit, spacecraft to Mars, and even astronauts to the Moon. America was undeniably the leader in space exploration, but the range of space activities was (by today's standards) relatively limited. In the 1980s, not only has the number of spacefaring nations increased, but so has the range of activities that

an interested nation might undertake.

The business of space has expanded and branched, and now encompasses such diverse and mature fields as remote sensing, microgravity materials research, commercial communications, and interplanetary exploration. It appears virtually impossible for a single nation to dominate in all space endeavors. Since the U.S. can no longer reasonably expect to lead the way in all activities, it is now important to adopt a strategy to strive for leadership in carefully chosen areas.

If nations engage in similar activities (occupy the same space on the matrix) the conditions exist for either rivalry or cooperation; if a nation engages in distinct activities (occupies a space alone), the conditions exist for uncontested leadership.

This matrix was used to broadly characterize the space programs of the United States and other spacefaring nations during two periods of the space age: (1) 1957 through 1977, illustrated by **Figure 3**; and (2) 1978 through 1990, illustrated by **Figure 4**.

The major programs, U.S. and non-U.S., were identified and placed in the appropriate squares. This is by no means a comprehensive compilation, but the selected activities are representative of space efforts during these periods. An admittedly subjective assessment was made of whether the public perceived the U.S. or non-U.S. efforts to be the leaders in a given square. Each square was then shaded either blue or red: blue if the U.S. was judged the leader, red if not.

A comparison of the two matrices graphically displays the difference between these two periods of time. In the early years of the space age, fewer areas were accessible and the U.S. was the clear leader in most; the matrix representing the 1980s illustrates the decline of U.S. leadership.

REGION OF SPACE \ LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	STAR PROBE	LUNAR OBSERVATORY		
OUTER SOLAR SYSTEM	NEPTUNE FLYBY-PROBE	CASSINI		
INNER SOLAR SYSTEM	MARS SAMPLE RETURN HUMAN EXPEDITION TO MARS		LUNAR BASE	
HIGH-EARTH ORBIT	LARGE SPACE STRUCTURES	ROBOTIC SERVICING	SPACE TRANSFER VEHICLE	SOLAR POWER SATELLITES
LOW-EARTH ORBIT	VARIABLE-G FACILITY	EARTH OBSERVING PLATFORMS	ON-ORBIT ASSEMBLY	MATERIALS PROCESSING
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	NATIONAL AEROSPACE PLANE	SHUTTLE II	ASSURED ACCESS AND RETURN	COMMERCIAL LAUNCH VEHICLES

Figure 2. Possible Programs to Capture Leadership after 1995

Examining the programs of the spacefaring nations shows the basic character of each. The U.S. space program has historically been composed of pioneering efforts – significant firsts and complex second efforts, which emphasized advanced research, technology, and exploration. The general trend can be characterized as revolutionary, producing spectacular events, rather than moderate, evolutionary advances. Even the United States Space Shuttle, though designed to be operational, was a revolutionary concept – it did not evolve from existing launch vehicles.

The Soviet space program, which is radically different from the American program, can be characterized as systematic and evolutionary. The primary focus is not on advanced research and technology, but on incrementally developed operational capabilities, achieved through a strong commitment to a robust infrastructure. The Soviets have steadily evolved toward this operational state and they are now beginning to build on that operational base to move slowly into the commercial arena.

The Europeans and the Japanese appear to be pursuing strategies that combine desires to pursue science in selected areas and to achieve commercial viability in others. The launch system Ariane, the remote-sensing satellite SPOT, and the Japanese JEM (which will be devoted to materials science research) are all examples of elements in these strategies.

These observations suggest that there is no one "correct" strategy; rather, there are many distinct strategic options. Clearly, each nation should choose and pursue a strategy which is consistent with its own national objectives.

What should our choice be? Do we want to mature our operational Earth-orbiting capabilities to a viable commercial enterprise? Should we continue our leadership role in solar system and deep-space exploration? Or should we focus on venturing ever further outward from Earth with human expeditions to the planets?

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	ORBITING ASTRONOMICAL OBSERVATORY-2 HIGH-ENERGY ASTRONOMY OBSERVATORY-1			
OUTER SOLAR SYSTEM	PIONEER			
INNER SOLAR SYSTEM	MARINER SURVEYOR 3 SEE LUNA APOLLO 8, 11 HELIOS VENERA VIKING 1	SURVEYOR 1 APOLLO 13 ZOND 3		
HIGH-EARTH ORBIT	SYNCOM 1,2,3 CTS INTELSAT	APPLICATIONS TECHNOLOGY SATELLITE	EARLY BIRD INTELSAT	WESTAR INTELSAT KOREASAT INMARSAT
LOW-EARTH ORBIT	ECHO 1 TIROS GEMINI ARIEL 1 SPUTNIK LANDSAT KOSMOS 1	EXPLORER 1 SOYUZ 4, 5 GEMINI APOLLO/SOYUZ	TIROS 1	
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	SATURN 1 SALYUT 1	SKYLAB SALYUT		

*Programs for which the U.S. is not primarily responsible are indicated by italics; areas in which its leadership is perceived are without color.

Figure 3. Leadership Matrix: Representative Achievements, 1957 to 1977

REGION OF SPACE / LEADERSHIP STAGE	PIONEER	COMPLEX SECOND	OPERATIONAL	COMMERCIALLY VIABLE
DEEP SPACE	HUBBLE SPACE TELESCOPE MIR KVANT MODULE INFRARED ASTRONOMICAL SATELLITE			
OUTER SOLAR SYSTEM	VOYAGER	GALILEO		
INNER SOLAR SYSTEM	INTERNATIONAL COMET EXPLORER HALLEY FLOTILLA	MAGELLAN YUGNAY LUNAR PHOBOS VEGA	VENERA	
HIGH-EARTH ORBIT		GLOBAL POSITIONING SATELLITE INERTIAL UPPER STAGE GLONASS	PAYLOAD ASSIST MODULE GLOBAL POSITIONING SATELLITE TDRS	COMMUNICATION SATELLITE INTELSAT
LOW-EARTH ORBIT		SATELLITE REPAIR SALYUT SPACELAB	MIR SALYUT	LANDSAT SPOT
SUPPORTING TECHNOLOGIES AND TRANSPORTATION	STS 1 THROUGH 4 USSR SHUTTLE	CTS ENERGIA HERMES	TITAN IV PROTON PROGRESS	ATLAS CENTAUR ARIANE TITAN IIID PROTON 2 DELTA LONG MARCH

*Programs for which the U.S. is not primarily responsible are indicated by italics; areas in which its leadership is perceived are without color.

Figure 4. Leadership Matrix: Representative Achievements, 1978 to 1990

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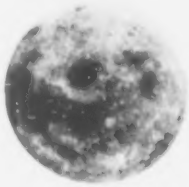


LEADERSHIP INITIATIVES

To energize a discussion of long-range goals and strategies for the civilian space program, four bold initiatives were selected for definition, study, and evaluation:

1. **Mission to Planet Earth**: a program that would use the perspective afforded from space to study and characterize our home planet on a global scale.

2. **Exploration of the Solar System**: a program to retain U.S. leadership in exploration of the outer solar system, and regain U.S. leadership in exploration of comets, asteroids, and Mars.

3. **Outpost on the Moon**: a program that would build on and extend the legacy of the Apollo Program, returning Americans to the Moon to continue exploration, to establish a permanent scientific outpost, and to begin prospecting the Moon's resources.

4. **Humans to Mars**: a program to send astronauts on a series of round trips to land on the surface of Mars, leading to the eventual establishment of a permanent base.

The intent is not to choose one initiative and discard the other three, but rather to use the four candidate initiatives as a basis for discussion. For this reason, it was important to choose a set of initiatives which spanned a broad spectrum of content and complexity.

The ground rules for this study are important to understand, since they influenced the detailed definition of the initiatives. The ground rules, set forward at the outset of this study, were:

- The initiatives should be considered *in addition* to currently planned NASA programs. They were not judged against, nor would they supplant, existing programs.
- Each initiative should be developed independently. There is, of course, considerable synergism between certain initiatives. For example, one possible progression for human exploration could be the development of a lunar outpost, followed by an expedition to Mars. However, in order to provide a clear starting point for discussion, the four were considered to be distinct.
- The initiatives should achieve major milestones within two decades.
- The Humans to Mars initiative should be assumed to be an American venture. It was beyond the scope of this work to consider joint U.S./Soviet human exploration.

The candidate initiatives were developed and presented to NASA management to: (1) evaluate the initiatives and their implications, and (2) promote a discussion of the attributes of each initiative to determine the elements which are most important to NASA and to the United States.

Each initiative was developed by a separate task group, which discussed the goals, milestones, and elements of the initiative, and then determined the requisite transportation, space facilities, and technologies. For each initiative, an "advocate" was identified to work with appropriate NASA personnel to develop programmatic details. These four advocates presented the strategies, scenarios, requirements, and rationale to senior NASA management.

Two initiatives, Mission to Planet Earth and Exploration of the Solar System, had a body of recent work from which to draw. The 1986 report of the Earth System Sciences Committee of the NASA Advisory Council, *Earth System Science: A Program for Global Change*, clearly states goals for the future observation of Earth. Two reports by the Solar System Exploration Committee of the NASA Advisory Council similarly articulate goals and recommendations for solar system exploration. Titled *Planetary Exploration through Year 2000: Part One: A Core Program*, and *Part Two: An Augmented Program*, these reports outline both a conservative, steady program for solar system exploration and a set of more challenging, exciting missions to be undertaken if resources to do so become available. The other two initiatives, Outpost on the Moon and Humans to Mars, did not have clearly delineated strategies available and no specific organization within NASA was dedicated to their advocacy.

An Earth-orbiting polar platform.

MISSION TO PLANET EARTH

Mission to Planet Earth is an initiative to understand our home planet, how forces shape and affect its environment, how that environment is changing, and how those changes will affect us. The goal of this initiative is to obtain a comprehensive scientific understanding of the entire Earth System, by describing how its various components function, how they interact, and how they may be expected to evolve on all time scales.

The challenge is to develop a fundamental understanding of the Earth System, and of the consequences of changes to that system, in order to eventually develop the capability to predict changes that might occur – either naturally, or as a result of human activity.

Background

With the launch of the first experimental satellites in the 1960s, NASA pioneered the remote sensing of Earth from space. Over the past two decades, the scientific community has concluded that Earth is in a process of global change, and scientists now believe that it is necessary to study Earth as a synergistic system. As stated in the Earth System Sciences Committee report cited earlier, "Global observations, new space technology, and quantitative models have now given us the capability to probe the complex, interactive processes of Earth evolution and global change." Interactive physical, chemical, and biological processes connect the oceans, continents, atmosphere, and biosphere of Earth in a complex way. Oceans, ice-covered regions, and the atmosphere are closely linked and shape Earth's climate; volcanism links inner Earth with the atmosphere; and biological activity significantly contributes to the cycling of chemicals (e.g., carbon, oxygen, and carbon dioxide) important to life. And now it is clear that human activity also has a major impact on the evolution of the Earth System.

Global-scale changes of uncertain impact, ranging from an increase in the atmospheric warming gases, carbon dioxide and methane, to a hole in the ozone layer over the Antarctic, to important variations in vegetation covers and in coastlines, have already been observed with existing measurement capabilities. The potentially major consequences, either detrimental or beneficial, suggest an urgent need to understand these variations.

We currently lack the ability to foresee changes in the Earth System, and their subsequent effects on the planet's physical, economic, and social climate. But that could change; this initiative would revolutionize our ability to characterize our home planet, and would be the first step toward developing predictive models of the global environment.

Strategy and Scenario

The guiding principle behind this initiative is to adopt an integrated approach to observing Earth. The observations from various sensors on platforms and satellites will be coordinated to perform global surveys and also to perform detailed observations of specific phenomena.

Mission to Planet Earth proposes:

1. To establish and maintain a global observational system in space, which would include experiments and free-flying platforms, in polar, low-inclination, and geostationary orbits, and which would perform integrated, long-term measurements.
2. To use the data from these satellites along with *in-situ* information and numerical modeling to document, understand, and eventually predict global change.

As illustrated in **Figure 5**, the global observational system would include a suite of nine orbiting platforms:

- Four sun-synchronous polar platforms: two provided by the United States and one each provided by the European Space Agency (ESA) and the Japanese National Space Development Agency (NASDA). The first platform would be launched in 1994 and all four platforms would be in orbit by 1997. These platforms would provide global polar coverage with morning and afternoon crossing times.
- Five geostationary platforms: three provided by the U.S. and one each by ESA and NASDA. These platforms would all be launched and deployed between 1996 and 2000.

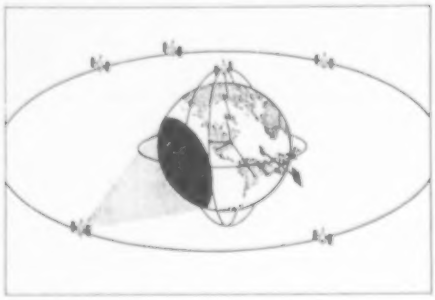


Figure 5. Mission to Planet Earth

Low-inclination, low-altitude payloads would also be included in the system. The Earth Radiation Budget Experiment satellite, launched from the Space Shuttle in 1984, and the synthetic aperture radar sensors, SIR-A and SIR-B, flown on the Shuttle in 1981 and 1984, are the types of experiments that would fall into this category. Another example would be a proposed Space Station-attached payload designed to obtain coverage of tropical rainfall with sampling at all local times.

The integrated system would measure the full complement of the planet's characteristics, including: global cloud cover, vegetation cover, and ice cover; global rainfall and moisture; ocean chlorophyll content and ocean topography; motions and deformations of Earth's tectonic plates; and atmospheric concentration of gases such as carbon dioxide, methane, and ozone.

Space-based observations would also be coordinated with ground-based experiments and the data from all observations would be integrated by an essential component of this initiative: a versatile, state-of-the-art information management system. This tool is critical to data analysis

and numerical modeling, and would enable the integration of all observational data and the development of diagnostic and predictive Earth System models.

This global observational system would be designed to operate for decades, serviced either by astronauts or robotic systems to ensure long life and to provide the continuing data collection, integration, and analysis required by this initiative.

Because of its international and interdisciplinary nature, the Mission to Planet Earth requires the strong support and involvement of other U.S. government agencies (particularly the National Science Foundation and the National Oceanic and Atmospheric Administration) and of our international partners. The roles of the various Federal agencies have been examined in detail by the Earth System Sciences Committee. NASA's responsibilities would include the information management system and platforms and experiments described previously. Most important, NASA would also provide the supporting technology, space transportation, space support services, and much of the scientific leadership.

Technology, Transportation, and Orbital Facilities

This initiative requires advances in technology to enhance observations, to handle and deliver the enormous quantities of data, and to ensure a long operating life. Sophisticated sensors and information systems must be designed and developed, and advances must be made in automation and robotics (whether platform servicing is performed by astronauts or robotic systems).

To achieve its full scope, this initiative requires the operational support of Earth-to-orbit and space transportation systems to accommodate the launching of polar and geostationary platforms. This does not represent a large number of additional launches, but it does require the capability to launch large payloads to polar orbit; Titan IVs would be used to accomplish this. Since the envisioned geostationary platforms would be lifted to low-Earth orbit, assembled at the Space Station, and then lifted to geosynchronous orbit with a space transfer vehicle, well-developed orbital facilities are essential. By the late 1990s, the Space Station must be able to support on-orbit assembly, and a space transfer vehicle must exist.

Summary

NASA, with its technical and scientific expertise, is uniquely suited to lead Mission to Planet Earth. Only from Earth orbit can we gain the perspective necessary to observe the Earth System and the interaction of its components on a global scale. We now understand what to observe and how to observe it. While we do not yet know how the data will piece together, the resulting Earth System models, developed and refined over years of study, are the important products of this initiative, and would establish NASA as a responsive agency ready to meet the challenge of a genuine time-critical need. Championing this initiative would establish the United States at the forefront of a world-recognized need to understand our changing planet.

The Comet Rendezvous Asteroid Flyby *spacecraft flies in formation with Comet Tempel 2.*

EXPLORATION OF THE SOLAR SYSTEM

This initiative would build on NASA's long-standing tradition of solar system exploration and would continue the quest to understand our planetary system, its origin, and its evolution. Solar system bodies are divided into three distinct classes: the primitive bodies (comets and asteroids), the outer (gas giant) planets, and the inner (terrestrial) planets. Each class occupies a unique position in the history of the solar system, and each is the target of a major mission in this initiative, which includes a comet rendezvous (the *Comet Rendezvous Asteroid Flyby* mission), a mission to Saturn *(Cassini)*, and three sample return missions to Mars. The centerpiece of the initiative is the robotic exploration of Mars; the first of these three automated missions would bring a handful of Mars back to Earth before the year 2000.

Background

In the 1960s and 1970s, exploration of the solar system was an important and visible component of the U.S. space program. Highly successful missions such as *Pioneer, Viking, and Voyager* made the United States the unchallenged leader in the exploration of the planets. Our spacecraft were consistently both the first and the best. While the Soviet Union concentrated most of its efforts on the exploration of Venus, the rest of the solar system was left to the United States.

But now almost a decade has elapsed between U.S. planetary missions – the last was *Pioneer Venus*, launched in 1978. *Galileo* (to Jupiter), *Magellan* (to Venus), and the *Mars Observer* are in line for launch between 1989 and 1992, but no other planetary missions have been approved. Although the successful *Voyager* missions to the outer planets clearly established U.S. leadership in exploration of the outer solar system, plans for the future beyond the *Galileo* mission are uncertain.

Other nations have recently begun to undertake innovative and challenging programs (the recent international flotilla to Halley's Comet is an excellent example). The Soviets have announced an ambitious program for the exploration of Mars which will culminate in a sample return mission, and the Europeans have set a long-term goal of returning a sample from a comet. Although currently scheduled U.S. missions will ensure that the United States will remain a leader in certain areas of solar system exploration through 1995, the position of the United States beyond 1995 is in question. This initiative would maintain U.S. leadership in exploration of the outer planets, and would regain and sustain U.S. leadership in the exploration of both the planet Mars and the primitive bodies of the solar system.

Strategy and Scenario

This initiative is based on the balanced strategy developed by the Solar System Exploration Committee of the NASA Advisory Council and elucidated in its two reports (cited previously) describing a Core Program and an Augmented Program for planetary exploration. The missions include:

1. The ***Comet Rendezvous Asteroid Flyby (CRAF)*** mission would investigate the beginnings of our solar system, studying a Main Belt asteroid and a comet, which represent the best-preserved samples of the early solar system. Because of their primordial nature, comets can provide critical clues about the processes that led to the origin and evolution of our solar system.

   The *CRAF* mission scenario is shown in **Figure 6**. After a 1993 launch and a six-month cruise, the spacecraft would fly past the asteroid Hestia at an altitude of about 10,000 kilometers. *CRAF*'s visual and infrared asteroid imaging systems would conduct investigations of Hestia's surface composition and structure. *CRAF* would then continue its journey for a rendezvous with a periodic comet, Tempel 2. The spacecraft would maneuver to within 25 kilometers of the comet's nucleus and begin a series of observations, which includes shooting two penetrators into the nucleus itself for detailed *in-situ* measurements. The spacecraft would fly in close formation with the comet until it nears the Sun and becomes active; then the spacecraft would maneuver farther away to observe the comet's coma and tail.
2. The ***Cassini*** mission would explore Saturn and its largest moon, Titan. The giant outer planets offer us an opportunity to address key questions about their internal structures and compositions through detailed studies of their atmospheres. Titan is an especially interesting target for exploration because the organic chemistry now taking place there provides the only planetary-scale laboratory for studying processes that may have been important in the prebiotic terrestrial atmosphere.

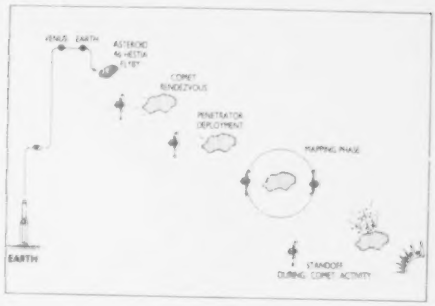


Figure 6.
The *Comet Rendezvous Asteroid Flyby* Mission

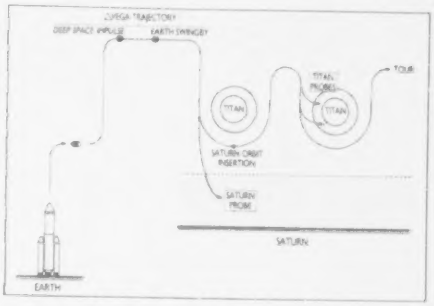


Figure 7.
The *Cassini* Mission

The *Cassini* mission proposed in this initiative would be a considerably expanded version of the *Cassini* mission considered by the Solar System Exploration Committee. (**Figure 7** shows the scenario for the baseline version of *Cassini*.) This expanded mission would be launched in 1998 for the long interplanetary voyage to arrive at Saturn in 2005 with a full array of investigative instruments. An orbital spacecraft and three probes would conduct a comprehensive three-year study of the planet and its rings, satellites, and magnetosphere. One atmospheric probe would be launched toward Titan. The expanded *Cassini* mission would also carry one probe to investigate the Saturnian atmosphere, and one semi-soft lander which would reach the surface of Titan.

3. The ***Mars Rover/Sample Return*** missions would, in journeys covering hundreds of millions of miles, gather samples of Mars and bring them back to Earth. Because of its relevance to understanding Earth and other terrestrial planets, and because it is the only other potentially habitable planet in our solar system, Mars is an intriguing target for exploration.

   The *Mars Rover/Sample Return* mission scenario is shown in **Figure 8**. It would involve a soft landing on the Martian surface, deployment of a "smart" surface rover to select and collect samples, delivery of the samples to an ascent vehicle, and transfer of the samples from Mars orbit to a return vehicle. The samples would then most likely be returned to a sample handling module on the Space Station for analysis.

   The initiative would include three such missions: two launched in 1996, probably sending redundant rovers and ascent vehicles to ensure return of a sample in 1999, and one launched in 1998/99 with return in 2001.

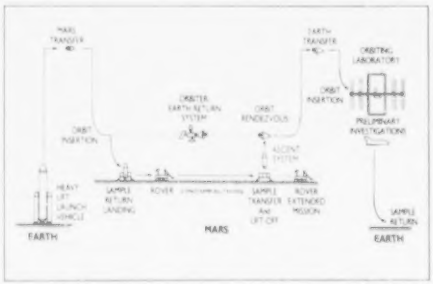


Figure 8.
The *Mars Rover/Sample Return* Mission

Technology, Transportation, and Orbital Facilities

As it is defined, this initiative places a premium on advanced technology and enhanced launch capabilities to maximize the scientific return. It requires aerobraking technology for aerocapture and aeromaneuvering at Mars, and a high level of sophistication in automation, robotics, and sampling techniques. Advanced sampling methods are necessary to ensure that geologically and chemically varied and interesting samples are collected for analysis.

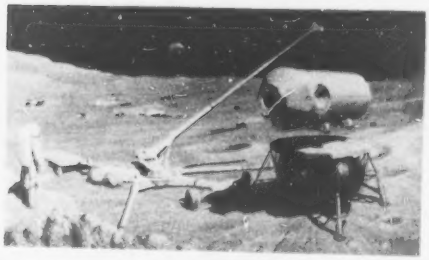
The Solar System Exploration initiative significantly benefits from improved launch capability in terms of the science returned from both the Mars and the *Cassini* missions. In fact, it is a heavy-lift launch vehicle that enables the full complement of three different probes to be carried in the expanded *Cassini* mission.

The Space Shuttle is not required for any of the missions in the initiative. The Space Station

would not be needed until 1999, when an isolation module may be used to receive the Martian samples.

Summary

This initiative adopts the broad strategy devised by the Solar System Exploration Committee for a balanced, systematic program of solar system exploration. Spacecraft would be sent to a comet (Tempel 2), an outer planet (Saturn), and an inner planet (Mars), to study representatives of each of the three distinct classes of solar system bodies in exquisite detail. The U.S. would take a bold step forward in the exploration of Mars and we would continue our leadership in exploration of the outer solar system. The scientific return over the next two decades would complement the outstanding solar system exploration program of the 1960s and 1970s and would offer additional insights into the evolution of our Earth and the solar system.



OUTPOST ON THE MOON

This initiative builds on the legacy of *Apollo* and envisions a new phase of lunar exploration and development – a phase leading to a human outpost on another world. That outpost would support scientific research and exploration of the Moon's resource potential, and would represent a significant extraterrestrial step toward learning to live and work in the hostile environments of other worlds.

Beginning with robotic exploration in the 1990s, this initiative would land astronauts on the lunar surface in the year 2000, to construct an outpost that would evolve in size and capability and would be a vital, visible extension of our capabilities and our vision.

Background

The Apollo Program was a great national adventure. We sent explorers to scout the cratered highlands and smooth maria of the Moon, and to bring samples collected on their trips back to laboratories on Earth. The world was fascinated by the *Apollo* missions and the information they obtained, and the samples provided scientists many exciting clues about the Moon's origin and chemical composition.

The *Apollo* era ended 15 years ago, before we could fully explore the promise of lunar science and lunar resources. But we learned that human beings can work on the surface of the Moon, and we laid the technical foundation to develop the scientific and engineering tasks for the next stages of exploration. This initiative would send the next generation of pioneers – to pitch their tents, establish supply lines, and gradually build a scientifically and technically productive outpost suitable for long-term habitation.

This initiative represents a sustained commitment to learn to live and work in space. As our experience and capabilities on the lunar surface grow, this extraterrestrial outpost will gradually become less and less dependent on the supply line to Earth. The first steps toward "living off the lunar land" will be learning to extract oxygen from the lunar soil, where it is plentiful, and learning to make construction materials. The lunar soil would eventually be a source of oxy-

gen for propellant and life-support systems, and a source of material for shelters and facilities.

The Moon's unique environment provides the opportunity for significant scientific advances; the prospect for gains in lunar and planetary science is abundantly clear. Additionally, since the Moon is seismically stable and has no atmosphere, and since its far side is shielded from the radio noise from Earth, it is a very attractive spot for experiments and observations in astrophysics, gravity wave physics, and neutrino physics, to name a few. It is also an excellent location for materials science and life science research because of its low gravitational field (one-sixth of Earth's).

Strategy and Scenario

This initiative proposes the gradual, three-phase evolution of our ability to live and work on the lunar surface.

Phase I: Search for a Site (1990s)
The initial phase would focus on robotic exploration of the Moon. It would begin with the launching of the *Lunar Geoscience Observer*, which will map the surface, perform geochemical studies, and search for water at the poles. Depending on the discoveries of the *Observer*, robotic landers and rovers may be sent to the surface to obtain more information. Mapping and remote sensing would characterize the lunar surface and identify appropriate sites for the outpost. The discovery of water or other volatiles would be extremely significant, and would have important implications for the location of a habitable outpost.

Phase II: Return to the Moon (2000-2005)
Phase II begins with the return of astronauts to the lunar surface. (The scenario is sketched in **Figure 9.**) The initiative proposes that a crew be transported from the Space Station to lunar orbit in a module propelled by a lunar transfer vehicle. The crew and equipment would land in vehicles derived from the transfer vehicle. Crew members would stay on the surface for one to two weeks, setting up scientific instruments, a lunar oxygen pilot plant, and the modules and equipment necessary to begin building a habitable outpost. The crew would return to the orbiting transfer vehicle for transportation back to the Space Station.

Over the first few flights, the early outpost would grow to include a habitation area, a research facility, a rover, some small machinery to move lunar soil, and a pilot plant to demonstrate the extraction of lunar oxygen. By 2001, a crew could stay the entire lunar night (14 Earth days), and by 2005 the outpost would support five people for several weeks at a time.

Phase III: At Home on the Moon (2005-2010)
Phase III evolves directly from Phase II, as scientific and technological capabilities allow the outpost to expand to a permanently occupied base. The base would have closed-loop life-support systems and an operational lunar oxygen plant, and would be involved in frontline scientific research and technology develop-

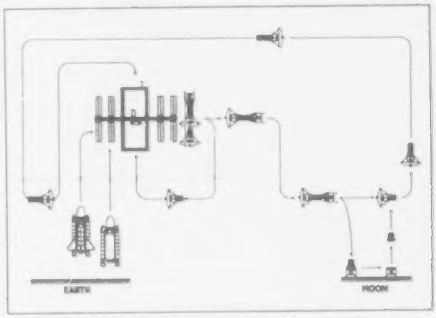


Figure 9.
Return to the Lunar Surface:
Piloted Sortie, Expendable Lander

ment. The program also requires the mobilization of disciplines not previously required in the space program: surface construction and transportation, mining, and materials processing.

By 2010, up to 30 people would be productively living and working on the lunar surface for months at a time. Lunar oxygen will be available for use at the outpost and possibly for propellant for further exploration.

Technology, Transportation, and Orbital Facilities

This initiative envisions frequent trips to the Moon after the year 2000 – trips that would require a significant investment in technology and in transportation and orbital facilities in the early 1990s.

The critical technologies for this initiative are those which would make human presence on the Moon meaningful and productive. They include life-support system technologies to create a habitable outpost; automation and expert systems and surface power technologies to make the outpost functional and its inhabitants productive; and lunar mining and processing technologies to enable the prospecting for lunar resources.

The transportation system must be capable of regularly transporting the elements of the lunar outpost, the fuel for the voyage, and the lunar crew to low-Earth orbit. This requires a heavy-lift launch vehicle and a healthy Space Shuttle fleet. The transfer of both cargo and crew from the Space Station to lunar orbit requires the development of a reusable space transfer vehicle. This and a heavy-lift launch vehicle will be the workhorses of the Lunar initiative.

The Space Station is an essential part of this initiative. As the lunar outpost evolves, the Space Station would become its operational hub in low-Earth orbit. Supplies, equipment, and propellants would be marshalled at the Station for transit to the Moon. It is therefore required that the Space Station evolve to include spaceport facilities.

In the 1990s, the Phase 1 Space Station would be used as a technology and systems test bed for developing closed-loop life-support systems, automation and robotics, and the expert systems required for the lunar outpost. The outpost would, in fact, rely on the Space Station for many of its systems and subsystems, including lunar habitation modules which would be derivatives of the Space Station habitation/laboratory modules.

Summary

This initiative represents a conceptual leap outward from Earth. The challenge is to tame and harness the space frontier – to go beyond *Apollo*, and explore the Moon for what it can tell us, and what it can offer us, as a research and development center and as a resource in itself. Exploring, prospecting, and settling are parts of our heritage and will most assuredly be parts of our future.

HUMANS TO MARS

This bold initiative is committed to the human exploration, and eventual habitation, of Mars. Robotic exploration of the planet would be the first phase and would include the return of samples of Martian rocks and soil. Early in the 21st Century, Americans would land on the surface of Mars; within a decade of these first piloted landings, this initiative would advance human presence to an outpost on Mars.

Background

The Red Planet has piqued our curiosity and stimulated our imaginations for decades. Our previous exploration of Mars has revealed a fascinating world of enormous mountains and deep canyons, and a surface etched by erosion during ancient floods. Mars may once have supported life; in any case, it is the only potentially habitable planet in our solar system besides Earth.

America has led the way in humanity's exploration of the worlds beyond our own planet. We have sent spacecraft to the outer reaches of the solar system, and our emissaries have walked on the surface of the Moon. The Humans to Mars initiative would greatly increase our understanding of the solar system, and would push the frontier of human presence ever further beyond the confines of Earth.

The United States has also led the way in the robotic exploration of Mars. The last visitor to that planet was the extremely successful *Viking* spacecraft, which landed on the Martian surface in 1976, and transmitted data to Earth until late in 1982. During the coming decade, humanity will learn more about Mars, but it will largely be the result of ambitious Soviet, not American, programs. Our single mission to Mars, the *Mars Observer*, to be launched in 1992, is a small spacecraft which will perform an important geochemical characterization of Mars while in orbit around the planet. Meanwhile, the Soviets have announced three separate missions to Mars before 1995, and the possibility of a sample return mission in the late 1990s.

This leadership initiative declares America's intention to continue exploring Mars, and to do so not only with spacecraft and rovers, but also with humans. It would clearly rekindle the national pride and prestige enjoyed by the U.S. during the *Apollo* era. Humans to Mars would be a great national adventure; as such, it would require a concentrated massive national commit-

ment – a commitment to a goal and its supporting science, technology, and infrastructure for many decades.

Strategy and Scenario

This initiative would:

1. Carry out comprehensive robotic exploration of Mars in the 1990s. The robotic missions would begin with the *Mars Observer*, include an additional *Observer* mission, and culminate in a pair of *Mars Rover/Sample Return* missions. These missions would perform geochemical characterization of the planet, and complete global mapping and support landing site selection and certification.
2. Establish an aggressive Space Station life sciences research program to validate the feasibility of long-duration spaceflight. This program would develop an understanding of the physiological effects of long-duration flights, of measures to counteract those effects, and of medical techniques and equipment for use on such flights. An important result would be the determination of whether eventual Mars transport vehicles must provide artificial gravity.
3. Design, prepare for, and perform three fast piloted round-trip missions to Mars. These flights would enable the commitment, by 2010, to an outpost on Mars.

The Mars missions described in this initiative are one-year, round-trip "sprints," with astronauts exploring the Martian surface for two weeks before returning to Earth. The chosen scenario significantly reduces the amount of mass which must be launched into low-Earth orbit, and by doing so brings a one-year round trip into the realm of feasibility. This is accomplished by splitting the mission into two separate parts – a cargo vehicle and a personnel transport – and judiciously choosing the launch date for each.

The Mars cargo vehicle minimizes its propellant requirements by taking a slow, low-energy trip to Mars. The vehicle would be assembled in low-Earth orbit and launched for Mars well ahead of the personnel transport, and would carry everything to be delivered to the surface of Mars plus the fuel required for the crew's trip back to Earth (**Figure 10**).

The personnel transport would be assembled and fueled in low-Earth orbit, and would leave for Mars only after the cargo vehicle had arrived in Mars orbit. It would carry a crew of six astronauts, crew support equipment, and propellant for the outbound portion of the trip (**Figure 11**). Once in Mars orbit, it would rendezvous with the cargo vehicle, refuel, and prepare for descent to the surface. The landing party would spend 10 to 20 days on the Martian surface, and then rendezvous with the personnel transport for the trip back to Earth orbit (**Figure 12**). Recovery in Earth orbit would return the crew to a Space Station rehabilitation facility (**Figure 13**). The round-trip time for this scenario is approximately one year.

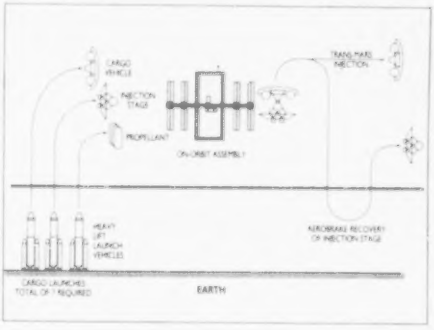


Figure 10.
Piloted Mars Sprint Scenario – Split Mission Option: Earth-Orbital Cargo Flight Operations

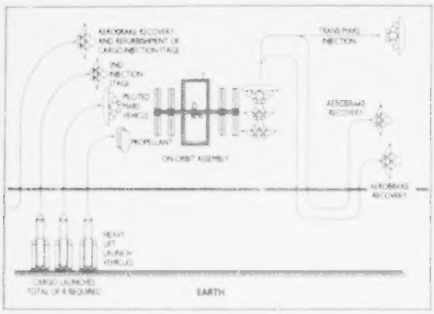


Figure 11.
Piloted Mars Sprint Scenario—Split Mission Option: Earth-Orbital Piloted Flight Operations

The initiative proposes three of these sprint missions, the third around the year 2010. By the second decade of the 21st Century, the U.S. would have the knowledge, the experience, and the technology base to begin developing an outpost on Mars.

Technology, Transportation, and Orbital Facilities

A significant, long-term commitment to developing several critical technologies and to establishing the substantial transportation capabilities and orbital facilities is essential to the success of the Mars initiative. The Mars expeditions require the development of a number of technologies, including aerobraking (which significantly reduces the amount of mass which must be lifted to low-Earth orbit), efficient interplanetary propulsion, automation and robotics, storage and transfer of cryogenics in space, fault-tolerant systems, and advanced medical technology. Technology development must be initiated immediately to support the timetable of this scenario.

Even with separate cargo and personnel vehicles, and technological advances such as aerobraking, each of these sprint missions requires that approximately 2.5 million pounds be lifted to low-Earth orbit. (In comparison, the Phase 1 Space Station is projected to weigh approximately 0.5 million pounds.) It is clear that a robust, efficient transportation system, including a heavy-lift launch vehicle, is required. The complement of launch vehicles must be able to lift the cargo and personnel required by the sprint missions to the Space Station in a reasonable period of time. Like the outpost on the Moon, this initiative requires a substantial investment in launch systems, for transport of both cargo and crew.

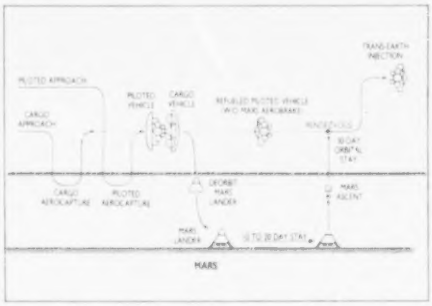


Figure 12.
Piloted Mars Sprint Scenario—Split Mission Option: Mars-Orbital/Surface Operations

The Phase 1 Space Station is a crucial part of this initiative. In the 1990s, it must support the critical life sciences research and medical technique development. It will also be the technology test bed for life-support systems, automation and robotics, and expert systems.

Furthermore, we must develop facilities in low-Earth orbit to store large quantities of propel-

lant, and to assemble large vehicles. The Space Station would have to evolve in a way that would meet these needs.

Summary

This initiative would send representatives of our planet to Mars during the first decade of the 21st Century. These emissaries would begin a phase of human exploration and reconnaissance that would eventually lead to the establishment of a permanent human presence on another world.

A successful Mars initiative would recapture the high ground of world space leadership and would provide an exciting focus for creativity, motivation, and pride of the American people. The challenge is compelling, and it is enormous.

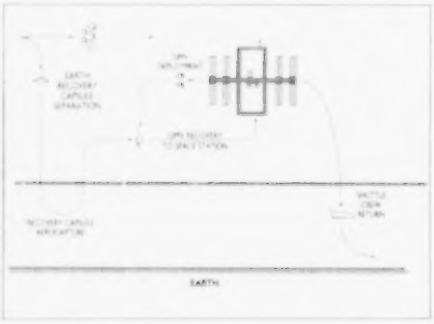
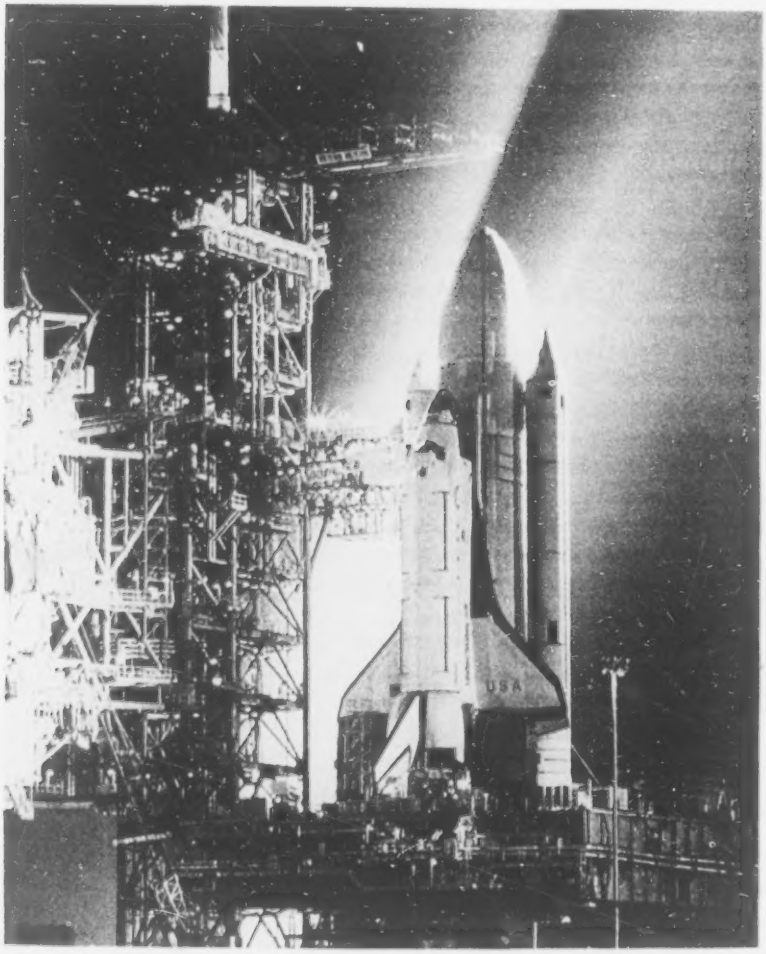


Figure 13.
Piloted Mars Sprint Scenario—Split Mission Option: Earth Recovery Operations



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PROGRAMMATIC ASSESSMENT

Each of the initiatives described in the previous section is a worthwhile program. Although each has something different to offer, each falls within the framework of NASA's vision, each builds on and extends existing capabilities, and each elicits the reaction, "America ought to be doing this." In the absence of fiscal and resource constraints, the United States would undoubtedly adopt all four. In the presence of those very real constraints, and the additional constraints imposed by the current state of our civilian space program, this course of action is not possible.

In its desire to revitalize the civilian space program, NASA must avoid the trap identified by the Rogers Commission during its investigation of the *Challenger* accident: "The attitude that enabled the agency to put men on the moon and to build the Space Shuttle will not allow it to pass up an exciting challenge – even though accepting the challenge may drain resources from the more mundane (but necessary) aspects of the program." The Commission further observed (in reference to the Shuttle flight rates): "NASA must establish a realistic level of expectation, then approach it carefully."

To establish a realistic level of expectation, NASA must consider the current condition of the space program, its strengths and limitations, and its capabilities for growth. Any bold initiative has to begin with and then build on today's space program, which unfortunately lacks some fundamental capabilities. For example, our most critical commodity, Earth-to-orbit transportation, is essential to each of the initiatives. But the Space Shuttle is grounded until at least June of 1988, and when it does return to flight status, the flight rate will be considerably lower than that projected before the *Challenger* accident (a four-Shuttle fleet is estimated to be capable of 12 to 14 flights per year).

In hindsight, it is easy to recognize that it was a crippling mistake to decree that the Space Shuttle would be this country's only launch vehicle. Several studies since the *Challenger* accident have recommended that the civilian space program include expendables in its fleet of launch vehicles. This strategy relieves some of the burden from the Shuttle, gives the country a broader, more flexible launch capability, and makes the space program less vulnerable in the event of an accident.

The problem of limited launch capability or availability will be magnified during the assembly and operation of the Space Station. Currently, NASA plans to use only the Space Shuttle to transport cargo and people to and from the Space Station. This places a heavy demand on the Shuttle (six to eight flights per year), but more important, it makes the Space Station absolutely dependent on the Shuttle. If Shuttle launches should be interrupted again in the mid-1990s, this nation must still have access to

TRANSPORTATION REQUIREMENTS

NASA transportation needs for the 1990s and beyond received considerable attention from the task group and committees examining agency goals and future program thrusts. The consensus of their findings is that if the Nation is to open a "Highway to Space," we must regain regular and assured access to space and expand launch capacity based on expendable and reusable vehicles.

"NASA should, on a most urgent basis, initiate a program to incorporate a diversified family of expendable launchers into its space flight program, to include a heavy-lift ELV. Payloads should be off-loaded from shuttle onto ELVs wherever possible." *Report of the Task Force on Issues of a Mixed Fleet*, 1987

"The U.S. should continue to expand its launch capacity based on a mixed fleet of expendable and reusable launch vehicles to preclude total reliance on any one launch system, so that the present manned and unmanned launchers will remain operationally healthy until the next generation of vehicles is fully developed." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"The use of a mixed launch fleet will allow humans to fly when they are needed on a mission and allow unmanned vehicles to be the carrier of choice for other missions... Diversity will also allow a better matching of the scientific requirements of a mission with the launch capability needed to meet those requirements, rather than forcing the mission to meet the constraints of a single inflexible launch system." *The Crisis in Space and Earth Science*, 1986

"The shuttle fleet will become obsolescent by the turn of the century. Reliable, economical launch vehicles will be needed to provide flexible, routine access to orbit for cargo and passengers at reduced costs ... to reduce space operation costs as soon as possible, the Commission recommends that three major space transport needs be met in the next 15 years: cargo transport to low Earth orbit; passenger transport to and from low Earth orbit; and round-trip transfer beyond low Earth orbit." *Pioneering the Space Frontier*, 1986

space and the means to transport cargo and people to and from the Space Station. The importance of this capability was emphasized by the National Commission on Space in its report, *Pioneering the Space Frontier*: "Above all, it is imperative that the US maintain a continuous ability to put both humans and cargo into orbit."

From now until the mid-1990s, Earth-to-orbit transportation is NASA's most pressing problem. A space program that can't get to orbit has all the effectiveness of a navy that can't get to the sea. America must develop a cadre of launch vehicles that can first meet the near-term commitments of the civilian space program and then grow to support projected programs or initiatives.

Expendable launch vehicles should be provided for payloads which are not unique to the Space Shuttle – this is required just to implement current plans and to satisfy fundamental requirements.

A Shuttle-derived cargo vehicle should be developed immediately. A Shuttle-derived vehicle is attractive because of its lift capacity, its synergism with the Space Transportation System, and its potential to be available for service in the early 1990s. This cargo vehicle would reduce the payload requirements on the Shuttle for Space Station support and would accelerate the Space Station assembly sequence.

The United States should also seriously consider the advisability of a crew-rated expendable to lift a crew capsule or a logistics capsule to the Space Station. The logistics vehicle, for Space Station resupply and/or instrument return, would be developed with autodocking and precision reentry capabilities. The crew capsule would carry only crew members and supplies, would launch (with or without a crew) on the expendable vehicle, would have autodocking capability, and might also be used for crew rescue.

TECHNOLOGY

Rebuilding the Nation's technology base is essential for the successful achievement of any long-term space goal. It is widely agreed that we are living off the interest of the *Apollo* era technology investment, and that it is time to replenish our technology reservoir in order to enhance our range of technical options.

"The Nation has allowed its technology base to erode, leaving it with little capability to move out in new directions should the need arise." Letter from Daniel J. Fink (Chairman, NASA Advisory Council) to James Fletcher, dated August 14, 1986

"Space technology advancement underlies any comprehensive future space activity. The present course is a status-quo caretaker path with no potential growth. New commitments are called for in key technologies such as propulsion, automation and robotics, flight computers, information systems, sensors, power generation, materials, structures, life support systems, and space processing. We support the recommendation by the National Commission on Space for a three-fold increase in this relatively low-budget but extremely important area of space technology advancement, especially in view of strong foreign commitments to such technology development." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"Research must be pursued on a broad front, to identify and quantify technical possibilities before their usefulness can be judged. Such a research and technology program is therefore properly conceived as opportunity generating, not directed toward applications." *Pioneering the Space Frontier*, 1986

These transportation capabilities are required just to launch, assemble, operate, and safely inhabit the Space Station, and to have some prospect of being able to support future initiatives.

Without sound, reliable Earth-to-orbit transportation available to lift sensors, spacecraft, scientists, and explorers to orbit, we will not be in a position to aggressively pursue either science or exploration. We have stated that transportation is not our goal – but it is essential to the successful pursuit of whatever goals we choose. If we do not make a commitment now to rebuild and broaden our launch capability, we will not have the option of pursuing any of the four initiatives described in the previous section.

The same can be said for advanced technology. The National Commission on Space observed that "NASA is still living on the investment made [during the *Apollo* era], but cannot continue to do so if we are to maintain United States leadership in space." Several recent studies concur, concluding that our technology base has eroded and technological research and development are underfunded. The technology required for bold ventures beyond Earth's orbit has not yet been developed, and until it is, human exploration of the inner solar system will have to wait.

Technologies explored by Project Pathfinder.

Project Pathfinder has been developed by NASA's Office of Aeronautics and Space Technology in conjunction with experts on the Lunar and Mars initiatives. Pathfinder would provide the technologies to enable bold missions beyond Earth's orbit: technology for autonomous systems and robotics, for lunar and planetary advanced propulsion systems, and for extraction of useful materials from lunar or planetary sources. It also deals in a significant way with the human ability to live and work in space, by developing technologies for life-support systems and the human/machine interface. Until advanced technology programs like Project Pathfinder are initiated, the exciting goals of human exploration will always remain 10 to 20 years in the future.

Life sciences research is also critical to any programs involving relatively long periods of human habitation in space. Because the focus of our life sciences research for the last several years has been on Space Shuttle flights, which only last for five to ten days, there has been no immediate need for a program to study the physiological problems associated with longer flights. Without an understanding of the long-term effects of weightlessness on the human body, our goal of human exploration of the solar system is severely constrained.

Before astronauts are sent into space for long periods, research must be done to understand the physiological effects of the microgravity and radiation environments, to develop measures to counteract any adverse effects, and to develop medical techniques to perform routine and emergency health care aboard spacecraft.

Project Pacer, developed by NASA's Office of

Space Science and Applications, is a focused program designed to develop that understanding and provide the physiological and medical foundation for extended spaceflight. This research would be conducted in laboratories and on Space Shuttle missions in preparation for the critical long-term experiments to be conducted on the Space Station.

Until the Space Station is occupied, and actual long-duration testing is begun, we will lack the knowledge necessary to design and conduct piloted interplanetary flights or to inhabit lower-gravity surface bases. Although the research conducted prior to the occupation of Space Station cannot provide definitive answers to several key questions, it is an essential precursor to the research and technology development on the Space Station.

LIFE SCIENCES RESEARCH

The prospect of an extended human presence in space on the Space Station and later on extended missions to the Moon or Mars requires a commitment to better understand and respond to biomedical, psychological, and human engineering challenges. Although there is great confidence that we will eventually establish a presence on other bodies in the solar system, there remains uncertainty in the medical community about the implications of such journeys for human health, safety, and productivity. A number of recent studies highlight concerns and identify areas requiring additional research.

"Space medicine is unique in the context of the other space sciences – primarily because, in addition to questions of fundamental interest, there is a need to address those issues that are more of a clinical or human health and safety nature ... if this country is committed to a future of humans in space, particularly for long periods of time, it is essential that the vast number of uncertainties about the effects of microgravity on humans and other living organisms be recognized and vigorously addressed. Not to do so would be imprudent at best – quite possibly, irresponsible." *A Strategy for Space Biology and Medical Science*, 1987

"Many crucial issues in the three major areas of health, life support, and operational capabilities remain to be resolved before the safety of humans working in space over months and years can be assured. Certain aspects of physiological adaptation to microgravity may be life-threatening, especially over the long-term ... Areas such as medical care, radiation protection, environmental maintenance, and human productivity are equally serious, but the research and development activities associated with these areas have at least begun on a modest scale. To neglect any of these areas could prove risky, and parallel research activities are recommended." *Advanced Missions with Humans in Space*, 1987

"Of paramount practical importance are human safety and performance. Long-duration flights on the Space Station will increase our understanding of the effects of the space environment on people and other living systems. Problems of bone demineralization and loss of muscle mass persist, and effective empirical solutions are unlikely to be found soon ... It is imperative that basic research on this problem continue, both on the ground and in space." *Pioneering the Space Frontier*, 1986

Both technology development and life sciences research are pacing elements in human exploration.

The four initiatives represent widely varying levels of complexity and commitment. As part of the development and evaluation of the initiatives, an assessment was performed to estimate their relative complexities and therefore their relative impacts on the agency and its resources. The initiatives, and results from related studies, were reviewed to identify the required technology, transportation, on-orbit facilities, and precursor science. This assessment yielded the elements comprising each initiative – the building blocks of that initiative.

The assessment sought to define the initiatives to a reasonable level of detail through 2010. At this time, the initiatives would be in different stages of development. All Earth observing platforms would be in space with their observing systems operating; they would be serviced periodically, and would continue to transmit data to Earth for years. The final mission of the Planetary initiative would be complete; this initiative is not defined past 2010. The Lunar outpost would be well established, with most surface elements developed and delivered; it would receive continuing logistics support, but would be somewhat self sustaining, and have considerable potential for growth and for support of further exploration activities. In 2010, the nation's Mars program would have just finished its human reconnaissance phase, and would be prepared to embark on the establishment of an outpost.

To provide a common starting point for each initiative, this analysis assumed the currently planned NASA space program as a foundation. That is, each initiative must be built from the foundation of a fleet of four Space Shuttles and a Phase 1 Space Station; everything else that would have to be added to accomplish the initiative, including additional Space Station modules, new transportation elements, unscheduled precursor science missions, etc., was assumed to be part of that initiative.

Some of the elements of each initiative would be developed solely for that initiative; many others could be common to other intitiatives as well. An example of the former is the lunar oxygen plant designed to extract oxygen from the lunar soil. Although similar technologies might eventually be needed at a Mars outpost, the element itself exists only in the Lunar initiative. An example of an element which could be common to several programs is the space transfer vehicle of the Earth initiative. Although it would lift geostationary platforms from the Space Station to their final orbit, this vehicle could also be used to deliver other cargo (unrelated to the Earth initiative) to geosynchronous orbit, or it could be the basis of a lunar transfer vehicle. Each initiative has elements which could be

	PLANETARY	EARTH	LUNAR	MARS
• EARTH TO ORBIT VEHICLES				
SPACE SHUTTLE	•	●	●	●
PERSONNEL CARRIER			●	●
HEAVY LIFT LAUNCH VEHICLE	●	●	●	●
EXPENDABLE LAUNCH VEHICLE	●	●	●	●
SIGNIFICANT RETURNED CARGO			●	●
• SPACE TRANSFER VEHICLES				
ORBITAL MANEUVERING VEHICLE	•	●	●	●
CABIN			●	●
TELEROBOTIC SERVICER		●	●	●
EXPENDABLE UPPER STAGES	●	●	●	●
GEOSTATIONARY TRANSFER VEHICLE		●		
CARGO TRANSFER VEHICLE			●	●
PERSONNEL TRANSFER VEHICLE			●	●
* REQUIRED TO RECOVER MARS SAMPLE				

Table 1.
Transportation Requirements for the Initiatives

common to other programs, as well as initiative-specific elements.

An overview of the transportation elements required for the initiatives is shown in **Table 1**. The Earth and Planetary initiatives make the most modest demands on transportation, in terms of both essential new capabilities and frequency of use. But each of the initiatives requires an Earth-to-orbit transportation system comprised of more than just a Space Shuttle fleet.

A heavy-lift launch vehicle is either enabling, or significantly enhancing, to all the initiatives. A Shuttle-derived vehicle would have sufficient

SPACE STATION EVOLUTION

The Phase I Space Station will be a permanently staffed "laboratory in space" by 1996. Other capabilities, such as an assembly station or a fueling depot, will not be included in the initial phase, but could be accommodated later if a need for those functions is clearly identified.

A key question for the not-too-distant future is "How should the Space Station evolve?" Since the Space Station is a means to pursue our goals, the answer depends on what those goals are. It is important to understand what each initiative demands of the Space Station. For example, the Planetary initiative makes few demands on the Space Station; the Mars initiative makes substantial demands.

NASA's Office of Space Station has set up a Strategic Plans and Programs Division whose charter is to understand how the Space Station would be required to evolve under a variety of scenarios for the future, and what provisions must be made in the design of the Phase I Space Station to ensure that the evolution is possible.

Space Station evolution workshops, held in September 1985 and July 1986, laid the foundation for understanding how to accommodate a variety of users whose requirements may not be compatible. These workshops recognized, for example, that a laboratory in space, featuring long-term access to the microgravity environment, might not be compatible with an operational assembly and checkout facility, as construction operations could disturb the scientific environment.

Artist's conception of the Phase I Space Station

Space Station evolution planning will include an assessment of the implications of each of the four initiatives. It is important to have specific scenarios, with a level of technical definition behind them, to serve as a basis for these assessments. It is also important that results from these assessments feed back into the initiative scenarios. This iterative approach is required to establish reasonable evolution scenarios and initiatives that are compatible with the proposed evolution.

capacity for the Earth and Planetary initiatives. It would also satisfy the requirements of the Mars and Lunar initiatives through the 1990s, although shortly after the turn of the century both would need a vehicle with a lift capacity of 150,000 to 200,000 pounds. This higher lift capacity is needed primarily to supply the large amounts of propellant required for each initiative (about 2.2 million pounds to low-Earth orbit for each Mars sprint mission; 200,000 pounds to low-Earth orbit for each lunar trek).

The Lunar and Mars initiatives also have a critical need for the capability to transport personnel to and from the Space Station. This need could be filled by a personnel module added to the Shuttle, or by some other personnel carrier. The additional crew members would perform on-orbit assembly of the cargo and crew vehicles. Although there is currently no good estimate of the size of the crew required to assemble and test a vehicle in orbit, it is likely that the Lunar initiative, if it d lops as projected in Phase III, would require more than 30 people in low-Earth orbit by the year 2010. It builds to this peak gradually, though, and the early assembly requirements (2000 to 2005) can be phased in slowly.

All the initiatives have other needs as well. The Planetary initiative's needs are limited to expendable stages, and possibly an Orbital Maneuvering Vehicle for the recovery of a returned Mars sample. The Earth initiative makes more substantial use of Earth-orbital transportation, including a transfer vehicle to lift fully assembled observing platforms from the Space Station to geosynchronous orbit, and sophisticated Orbital Maneuvering Vehicles to aid in platform servicing. The Lunar and Mars initiatives are more demanding. Both are likely to require Orbital Maneuvering Vehicles to transport personnel from the Space Station to orbital assembly sites. Most significant, both require substantial space transfer vehicles to transport crews from low-Earth orbit to either the Moon or Mars. Although the lunar transfer vehicle could be a derivative of a transfer vehicle to geosynchronous orbit (or vice versa), at this time it appears that the Mars transfer vehicle will demand a different design.

The orbital facilities required for each initiative are shown in **Table 2**. The Planetary initiative has limited requirements in this area; the other three have extensive needs that begin with the Phase 1 Space Station. The Phase 1 Space Station includes polar platforms and attached payloads for the Earth initiative; it serves as a technology and systems test bed for the Lunar initiative; and it will be a crucial laboratory for life sciences research and technology development for the Mars initiative.

	PLANETARY	EARTH	LUNAR	MARS
• LOW-EARTH ORBIT FACILITIES				
PHASE 1 SPACE STATION		●	●	●
SPACE STATION ADDITIONS				
LIFE SCIENCE RESEARCH				●
SAMPLE ISOLATION	●			●
SPACE TRANSFER VEHICLE ASSEMBLY AND OPERATIONS			●	●
ADDITIONAL CREW			●	●
PROPELLANT STORAGE			●	●
POLAR PLATFORMS		●		
• GEOSTATIONARY FACILITIES				
PLATFORMS		●		
COMMUNICATIONS			●	●
• LUNAR FACILITIES				
SERVICE STATION			●	
COMMUNICATIONS			●	
• MARS FACILITIES				
CARGO VEHICLE ORBITAL OPERATIONS				●

Table 2.
Orbital Facilities Required for the Initiatives

All the initiatives require that the Space Station evolve additional capabilities, but the needs of the Planetary initiative (a sample return module) and the Earth initiative (servicing capability, operation of a space transfer vehicle) are relatively modest. The Lunar initiative requires gradual evolution to support the assembly, servicing, and checkout of lunar transfer vehicles. This requires more people in orbit (and therefore more Space Station modules and logistics traffic), spaceport facilities, and a propellant depot. The Mars initiative also relies on those spaceport facilities and additional crew accommodations, and although it will not occur quite as soon as in the Lunar initiative, the assembly of the large Mars cargo and piloted vehicles will be a significant task.

The Lunar initiative includes significant surface facilities such as habitation modules, laboratory modules, and an oxygen plant; the Mars initiative looks toward an eventual outpost (after 2015), but while similar surface facilities would be necessary at that time, they have not been included in the assessment to 2010. The Lunar and Mars initiatives both require landers, ascent vehicles, and rovers. These would most likely use some common technologies and subsystems, but they would not be identical.

The initiatives also require investments in technology development, and investments in institutional and human resources. This support early in the life of an initiative is vital to its success. The level of investment required is directly proportional to the magnitude and complexity of the initiative. The Earth and Planetary initiatives would be expected to have relatively modest needs; the Lunar and Mars initiatives would demand substantial technology development programs, and significant increases in highly skilled personnel and institutional facilities. The need for a dedicated, enthusiastic, and technically competent workforce must not be minimized; the Lunar and Mars initiatives would both require a significant increase in human resources.

The current level of definition of the initiatives, particularly the Lunar and Mars initiatives, is not adequate to reasonably estimate their costs. But while it was not appropriate to attempt to determine the absolute level of resources required by each, it was reasonable to estimate the relative levels through 2010. For each initiative, after the elements not included in current NASA plans were identified, the mass and size of each were estimated in order to determine the transportation requirements for that initiative. There was no attempt, at this early stage, to optimize the transportation system.

Figure 14 compares the resources required by the four initiatives during the next five years. It is important to understand the level of effort needed to support a new initiative during this period, since the country will also be relying on the civilian space program to return the Shuttle to flight, to reinvigorate its transportation system, and to continue serious preparations for the Space Station.

The Lunar, Earth, and Planetary initiatives would take about the same level of investment through 1992. The investment in the Lunar initiative would be primarily in technology and in early transportation development; in the Earth initiative, it would be largely in the development of the polar platforms, data handling system, and transportation; in the Planetary initiative, it would be primarily in technology, and in readying the *Comet Rendezvous Asteroid Flyby* mission for a 1993 launch.

The Mars initiative requires the largest commitment in the early years. This would be primarily an investment in transportation elements and in life science related additions to the Space Station. Transportation and Space Station use have not been optimized, so some reduction might be possible. The message, however, would not

change: the country would have to make a major investment in the next five years to land people on Mars in 2005.

The complexity of both the Lunar and Mars initiatives in the year 2000 demands technology developments early in the program. Thus, through 1992 the majority of the Lunar initiative, and a significant portion of the Mars initiative, would be comprised of those technology activities which lay the groundwork for the initiative. Like early work in transportation, there is considerable synergism in the early technology requirements of these two initiatives.

Figure 15 compares the initiatives through 2010. The Lunar and Mars initiatives are nearly an order of magnitude greater in programmatic scope than the Planetary and Earth initiatives. The levels of investment in the Earth and Planetary initiatives peak in the early-to-mid-1990s, and then decrease to levels which remain fairly constant through the first decade of the next century. The Lunar initiative does not require extraordinary resources through 1992, but the commitment builds substantially in the mid-1990s. It peaks in about 2000, at the time of this initiative's first human landing, and stays high through 2010 as the outpost is developed into a permanent base. The total level of effort through 2010 is large, and reflects the ambitious approach to the construction of the lunar base. However, the nature of this initiative allows considerable flexibility. For example, the outpost materials could be delivered to the surface rapidly or at a more deliberate pace; certain capabilities of the outpost could be emphasized and developed before others; or the transition from a temporarily occupied outpost to a large

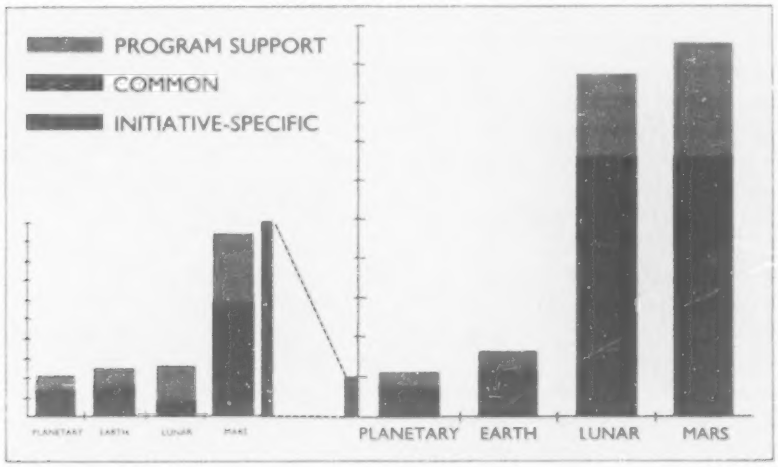

Figure 14.
Resources Required by Initiatives through 1992

Figure 15.
Resources Required by Initiatives through 2010

permanently staffed base could be delayed. Any of these options would significantly reduce the investment through 2010.

Although the Mars initiative offers the greatest amount of human and technological drama, it also demands the greatest investment. The Mars initiative definition included only those elements required for the three sprint missions, the last in 2010, so the level of investment shown is artificially low between 2005 and 2010. The magnitude of the initiative indicates a large commitment of resources, and the timescale dictates that the investment peak in about 2000.

It is possible to reduce the early investment to a level comparable to that of the other three initiatives by allowing the first human landing to occur in 2010, rather than in 2005. The 2005 landing was selected at the outset to achieve the major milestone within two decades, but this analysis suggests that this ground rule may not be appropriate for the Mars initiative.

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EVALUATION OF INITIATIVES

To this point, we have been considering four specific initiatives, each of which would, if adopted, provide leadership in a particular area of space endeavor. Now it is important to differentiate between an initiative and a strategy. A strategy provides an overall framework and direction; it identifies and prioritizes goals, and defines a course to attain them. An initiative should be an element of a strategy; a part, but only a part, of the larger picture. Initiatives would, of course, be best judged in the context of a strategy.

A process to define and evaluate candidate strategies for the civilian space program is being developed at NASA. This process will seek to identify possible strategies, then assess the likelihood of success and possible implications of each. They will be evaluated in relation to the existing and projected environment, and to the various conditions which may influence their success, such as:

- NASA's strengths, its weaknesses, and its culture
- External threats to U.S. leadership
- Opportunities to exercise leadership
- Optimistic and pessimistic scenarios of uncontrollable factors which influence NASA and its ability to carry out its charter
- The existing U.S. space policy

A successful Mars Rover/Sample Return *mission blasts off, carrying its cargo of Martian samples back to Earth.*

As potential strategies are modified in light of these factors, the result should be a set of two or three distinct, viable strategies whose resource requirements, threats to success, and implications to NASA and the nation are well defined and understood. Although this process is being developed at NASA, it is not NASA's role to determine the overall strategy for the nation's civilian space program; that must be a national decision. NASA should, however, be prepared to present viable options. The potential benefit of this process is evident. It can result in a cohesive strategy that is consistent with national goals, is based on a realistic appraisal of NASA's strengths and weaknesses and the nation's willingness to pursue it, and is resilient to changes in the international environment.

Ideally, of course, a strategy would already be in place. Then each initiative could be judged in light of its compatibility with the overall plan.

While stressing the need for a comprehensive strategy, we can nevertheless conduct a preliminary assessment of the initiatives, recognizing that the important considerations are the quality of the program, NASA's ability to carry it out, and the public's willingness to support it. In the process of this evaluation, we can see the elements of a potential strategy begin to emerge.

Exploration of the Solar System

In the 1960s and 1970s, planetary exploration was a vital and important component of the United States space program. However, while other nations are now vigorously pursuing solar system exploration, the U.S. has launched no planetary missions since 1978.

What does the next decade hold in store? The Soviets have announced their intent to launch three ambitious flights to Mars by 1995, and a Mars sample return mission by 2000. If they are successful with their new-generation spacecraft, and can continue to forge cooperative agreements with European nations, they will clearly have the greater momentum in the exploration of Mars by the mid-1990s.

The Chairman of the NASA Advisory Council's Solar System Exploration Committee has expressed his concern about more than the exploration of Mars: "If we do not continue to carry out these challenging missions to the outer planets and comets and asteroids, we will quickly lose the limited momentum still remaining."

The Solar System Exploration Committee has devised a strategy for planetary exploration through the year 2000, which presented "the minimum-level program that could be carried out in a cost-effective manner, and would yield continuing return of scientific results." NASA should embrace this Core Program.

The *Mars Rover/Sample Return* mission is the centerpiece of the Solar System Exploration Committee's recommended augmentation to its Core Program. This is a mission of bold scientific exploration and high technological drama, and a necessary precursor to the human exploration of Mars. The option for a 1998 launch (two years later than the 1996 date proposed in the initiative) should be preserved.

Although the *Mars Rover/Sample Return* was presented as a U.S. mission in this initiative, it could be performed in cooperation with our allies and/or in coordination with the Soviet Union. In fact, planetary exploration is well suited to international cooperation. The U.S. could benefit significantly by coordinating its *Mars Observer* with the three sophisticated Soviet missions to be launched for Mars over the next seven years. Coordination of these early flights, and exchange of resulting data, would leave the U.S. better prepared to undertake a *Mars Rover/Sample Return* mission, whether in coordination with the Soviets or alone.

Planetary exploration need not be NASA's primary focus, but it offers opportunities to exercise leadership in the international arena through organizing and participating in coalitions to achieve objectives which are consistent with U.S. goals, and it can provide important precursor information for either of the larger human exploration initiatives.

Robotic planetary exploration should be actively supported and nurtured within NASA. Although it does not have the immediate relevance of the Mission to Planet Earth, or the excitement of human exploration, it is fundamental science that challenges our technology, extends our presence, and gives us a glimpse of other worlds. As such, it enjoys widespread public interest and support. Although not necessarily at the pace suggested in this initiative, planetary exploration must be solidly supported through the 1990s.

Mission to Planet Earth

Mission to Planet Earth is not the sort of major program the public normally associates with an agency famous for *Apollo*, *Viking*, and *Voyager*. But this initiative is a great one, not because it offers tremendous excitement and adventure, but because of its fundamental importance to humanity's future on this planet.

This initiative directly addresses the problems that will be facing humanity in the coming decades, and its continuous scientific return will produce results which are of major significance to all the residents of the planet. The benefits are clear to a public that is increasingly concerned about global environmental problems like ozone depletion, buildup of greenhouse gases, and acidification of lakes and forests. And as the environment and its preservation become more pressing issues, the initiative retains its importance for many generations to come.

For this reason it should enjoy sustained public and Congressional support and interest. The U.S. is the only country currently capable of leading a Mission to Planet Earth, but the program is designed around, and requires, international cooperation. Admittedly, the initiative's international scope could complicate its coordination and implementation, but the concept embodied in the initiative enjoys widespread international support. As more and more countries are facing ecological problems, there is increasing interest in a global approach. In fact, this concept is supported by several international organizations, and may emerge as a theme for the International Space Year, 1992. This initiative represents an important opportunity for the United States to exercise leadership in an increasingly significant area.

As the Earth System Sciences Committee suggests, NASA is a natural leader for a Mission to Planet Earth. The National Science Foundation and the National Oceanic and Atmospheric Administration will play important roles, and interagency coordination is crucial. But since the major focus is on observations from space and the coordination and analysis of these (and ground-based) observations, NASA is uniquely suited to lead the effort. It is a natural use for, and extension of, our low-Earth orbital facilities and capabilities, and would not severely drain resources from existing programs. This is an initiative well within NASA's

capabilities, and could be carried out with our traditional commitment to excellence.

Should NASA do it? Virtually everyone exposed to this initiative recognized its fundamental importance, and agreed that "whatever we do, we have to do this"; but some felt it may not be bold and visionary enough to stimulate the increased funding necessary. The National Commission on Space conducted numerous public sessions on the space program, and solicited and received comments from a wide cross-section of Americans. The Commission's report lists a series of points "brought forward repeatedly" in those public sessions. One of these was the concern that "any new push into space must supplement living on Earth.... Don't abandon our home planet!"

Plans are already under way within NASA to undertake a subset of this program. The Earth Observing System, which consists of two NASA polar platforms, is being coordinated with the corresponding activities of the European Space Agency and Japan. The first NASA platform is part of the Phase 1 Space Station. The second platform, the instruments, and the payloads remain unapproved. And although the Earth Observing System would represent a major start, it is not sufficient to fulfill all the objectives of this initiative. Critical activities for the immediate future include the coordination of Federal agencies, and the strengthening of international agreements to facilitate the coordination of this international effort.

NASA should embrace Mission to Planet Earth. This initiative is responsive, time-critical, and shows a recognition of our responsibility to our home planet. Do we dare apply our capabilities to explore the mysteries of other worlds, and not also apply those capabilities to explore and understand the mysteries of our own world – mysteries which may have important implications for our future on this planet?

Humans to Mars

Exploring, prospecting, and settling Mars are clearly the ultimate goals of the next several decades of human exploration. But what strategy should be followed to attain those goals?

Any expedition to Mars is a huge undertaking, which requires a commitment of resources which must be sustained over decades. This task group has examined only one possible scenario for a Mars initiative – a scenario designed to land humans on Mars by 2005. This timescale requires an early and significant investment in technology; it also demands a heavy-lift launch vehicle, a larger Shuttle fleet, and a transportation depot at the Space Station near the turn of the century. This would require an immediate commitment of resources and an approximate tripling of NASA's budget during the mid-1990s.

More important, NASA would be hard pressed to carry the weight of this ambitious initiative in the 1990s without severely taxing existing programs. NASA's available resources were strained to the limit flying nine Shuttle flights in one year. It will be difficult to achieve the operations capacity to launch and control 12 to 14 Shuttle flights per year, and assemble, test, and continuously operate a Space Station in the mid-1990s. It would not be wise to embark on an ambitious program whose requirements could overwhelm those of the Shuttle and Space Station during the critical next decade.

This suggests that we should revise the ground rules and consider other approaches to human exploration of Mars. One alternative is to retain the scenario developed here, but to proceed at a more deliberate (but still aggressive) pace, and allow the first human landing to occur in 2010. This spreads the investment over a longer period, and though it also delays the significant milestones and extends the length of commitment, it greatly reduces the urgency for Space

Station evolution and growth, and consequently for transportation capabilities as well.

We must pursue a more deliberate program; this implies that we should avoid a "race to Mars." There is the very real danger that if the U.S. announces a human Mars initiative at this time, it could escalate into another space race. Whether such a race was real or perceived, there would be constant pressure to set a timetable, to accelerate it if possible, and to avoid falling behind. Schedule pressures, as the Rogers Commission noted, can have a very real, adverse effect. The pressure could make it difficult to design and implement a program which would have a strong foundation and adequate momentum to sustain itself beyond the first few piloted missions. This could turn an initiative that envisions the eventual development of a habitable outpost into another one-shot spectacular. Such a dead-end venture does *not* have the support of most NASA personnel. Neither, according to the National Commission on Space, does it have the support of the public. A "theme brought forward repeatedly" in the Commission's extensive public sessions was "a strong wish that our next goal for piloted space activity not be another *Apollo* – a one-shot foray or a political stunt."

THE OFFICE OF EXPLORATION

During the majority of this work, there was no focal point within NASA for studies on human exploration. Recognizing this deficiency, and adopting one of the early recommendations of this study, the NASA Administrator has established the Office of Exploration to fund, direct, and coordinate studies related to human exploration.

Both of the human exploration initiatives described in this work were generated in a workshop or task force environment. The three to four months devoted to their formulation were adequate only to develop the starting point for in-depth studies. The Office of Exploration will be responsible for coordinated mission studies to develop these and other scenarios, to assess mission concepts and schedules, and to study trade-offs in requirements, technology, transportation, and facilities utilization. Advanced technology and transportation requirements cannot be developed in a vacuum. These mission studies will provide a context for planning technology and transportation development and Space Station evolution (and studies in these areas will, of course, feed back into the mission scenarios).

The establishment of the Office of Exploration was an important step. Adequate support of the Office will be equally important, and will be an indication of the commitment to long-term human exploration. There is some concern among observers that the Office was created only to placate critics, not to provide a serious focus for human exploration. Studies relating to human exploration of the Moon or Mars currently command only about .03 percent of NASA's budget (approximately 1 dollar out of 3000); this is not enough.

The scenario described in this report is a rational, sustained program, leading to an outpost and eventual permanent base on Mars. But there is some fear that it is susceptible to transformation into a stunt. This could mortgage the viable space program we hope to have in the 1990s for a "spectacular," which may have few lasting benefits.

Settling Mars should be our eventual goal, but it should not be our next goal. Sending people to and from Mars is not the only issue involved. Understanding the requirements and implications of building and sustaining a permanent base on another world is equally important. We should adopt a strategy of natural progression which leads, step by step, in an orderly, unhurried way, inexorably toward Mars.

Outpost on the Moon

The Lunar initiative is a logical part of a long-range strategy for human exploration. The National Commission on Space recommended that the U.S. follow a "natural progression for future space activities within the solar system," and concluded that the natural progression of human exploration leads next to the Moon.

The establishment of a lunar outpost would be a significant step outward from Earth – a step that combines adventure, science, technology, and perhaps the seeds of enterprise. Exploring and prospecting the Moon, learning to use lunar resources and work within lunar constraints, would provide the experience and expertise necessary for further human exploration of the solar system.

The Lunar initiative is a major undertaking. Like the Mars initiative, it requires a national commitment that spans decades. It, too, demands an early investment in advanced technology, Earth-to-orbit transportation, and a plan for

Space Station evolution. Even considering its gradual evolution over the first five years, the ambitious buildup of the lunar outpost envisioned in this scenario would require a high level of effort in the mid-to-late 1990s, and would place substantial demands on transportation and orbital facilities. This is a period when resources may be scarce.

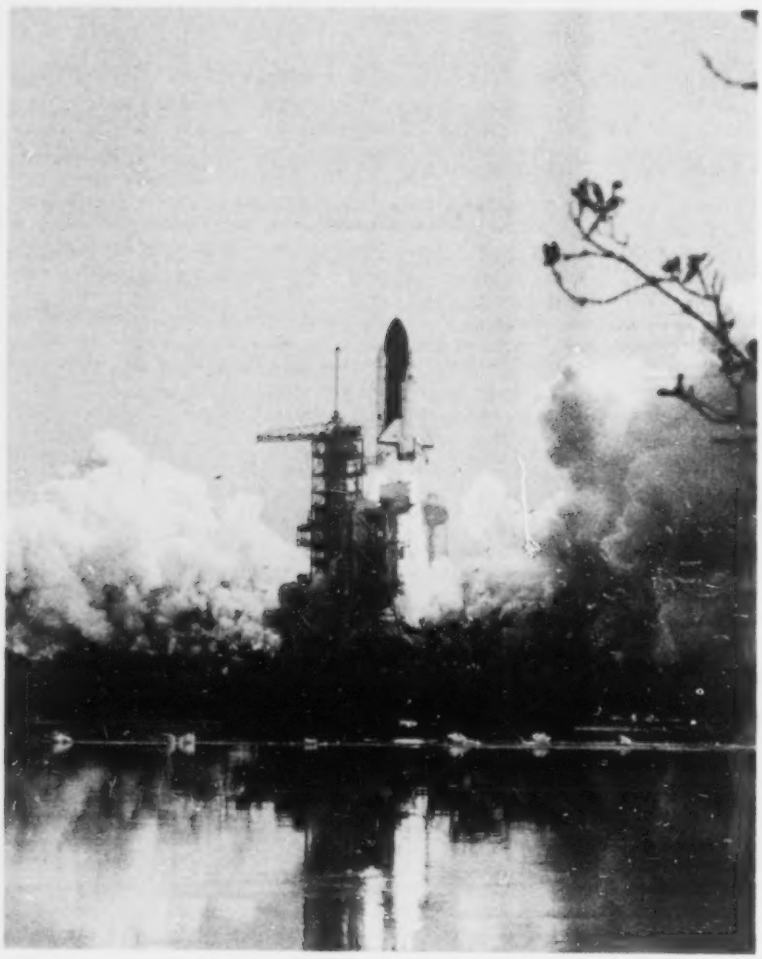
However, this initiative is quite flexible. Its pace can be controlled, and more important, adapted to capability. It is possible to lay the foundation of the outpost in the year 2000, then build it gradually, to ease the burden on transportation and Space Station at the turn of the century.

The Lunar initiative is designed to be evolutionary, not revolutionary. Relying on the Space Station for systems and subsystems, for operations experience, and for technology develop-

ment and testing, it builds on and gradually extends existing capabilities. Many of the systems needed for reaching outward to Mars could be developed and proven in the course of work in the Earth-Moon region. It is not absolutely necessary to establish this stepping stone, but it certainly makes sense to gain experience, expertise, and confidence nearer Earth first, and then to set out for Mars.

This study did not include an assessment of the level of public support for these initiatives. However, there is considerable sentiment that *Apollo* was a dead-end venture, and we have little left to show for it. Although this task force found some who dismissed this initiative because "we've been to the Moon," it found many more who feel that this generation should continue the work begun by *Apollo*.

Although explorers have reached the Moon, the Moon has not been fully explored. This initiative would push back frontiers, not to achieve a blaze of glory, but to explore, to understand, to learn, and to develop; it would place the Apollo Program into a broader context of continuing exploration, spanning several generations of Americans. And it fits beautifully into a natural progression of human expansion that leads "from the highlands of the Moon to the plains of Mars."



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CONCLUSION

Over the last 25 years, as a result of the success of programs like *Apollo*, *Skylab*, *Viking*, *Voyager*, and the Space Shuttle, the American public has come to expect this country to lead the world in space science, space exploration, and space enterprise. But during the 1980s, membership in the once-exclusive club of spacefaring nations has grown, and our leadership is being challenged in many areas.

In today's world, America clearly cannot be the leader in all space endeavors. But we will be the leader in very few unless we move promptly to develop a strategy to regain and retain leadership in those areas we deem important.

Leadership results from both the capabilities a country has acquired and the active demonstration of those capabilities. Thus, the strategy we choose must lay a strong foundation of scientific research and technology development, and must include visible, significant accomplishments that demonstrate the successful pursuit of our stated goals.

To stimulate a discussion of the future of the U.S. civilian space program, four potential leadership initiatives were developed. Each fits comfortably under the umbrella of NASA's charter, each contains visible milestones within the next two decades, and each requires a solid foundation of technology, transportation, and orbital facilities.

It would not be good strategy, good science, or good policy for the U.S. to select a single initiative, then pursue it single-mindedly. The pursuit of a single initiative to the exclusion of all others results in leadership in only a limited range of space endeavor.

A strategy for the U.S. space program must be carefully selected to be consistent with our national aspirations and consistent with NASA's capabilities. It is not NASA's role to determine the strategy for the civilian space program. But it is NASA's role to lead the debate, to propose technically feasible options, and to make thoughtful recommendations.

It is in this spirit that we suggest the outline of one strategy – a strategy of evolution and natural progression. The strategy would begin by increasing our capabilities in transportation and technology – not as goals in themselves, but as the necessary means to achieve our goals in science and exploration. The most critical and immediate needs are related to advanced transportation systems to supplement and complement the Space Shuttle, and advanced technology to enable the bold missions of the next century. Until we can get people and cargo to and from orbit reliably and efficiently, our reach will exceed our grasp; until we begin the technologies proposed by Project Pathfinder, the realization of our aspirations will remain over a decade away.

The strategy emphasizes evolving our capabilities in low-Earth orbit, and using those capabilities to study our own world and explore others. With these capabilities, we would position ourselves to lead in characterizing and understanding planet Earth; we would also position ourselves to continue leading the way in human exploration.

According to the NASA Advisory Council's Task Force on Goals, "Recognized leadership absolutely requires the expansion of human life beyond the Earth, since human exploration is one of the most challenging and compelling displays of our spacefaring abilities."

We should explore the Moon for what it can tell us, and what it can give us – as a scientific laboratory and observing platform, as a research and technology test bed, and as a potential source of important resources. While exploring the Moon, we would learn to live and work on a hostile world beyond Earth. This should be done in an evolutionary manner, and on a time scale that is consistent with our developing capabilities.

The natural progression of human exploration then leads to Mars. There is no doubt that exploring, prospecting, and settling Mars should be the ultimate objectives of human exploration. But America should not rush headlong toward Mars; we should adopt a strategy to continue an orderly expansion outward from Earth.

The National Commission on Space urges 21st Century America "To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars." The United States space program needs to define a course to make this vision a reality.

EDUCATION

An informed public is essential to both the near-and long-term interests of the nation's civilian space program. The public needs an appropriate base of knowledge of scientific and technological issues in order to make educated decisions on space-related goals. Additionally, today's educational system must produce the high caliber scientists, engineers, technicians, social scientists, and humanists that will actually manage the large-scale space programs that are now envisioned. This means capturing the imaginations and interests of young people at an early stage in their educational careers and encouraging them to pursue studies that will prepare them to actively participate in the space program.

"Unless the youth of this nation are strongly motivated to seek their careers in the often difficult fields of science and technology – of which space is a particularly exciting and rewarding constituent – no amount of federal program emphasis can by itself sustain a long-term leadership role for the U.S. in civil space activities." *U.S. Civil Space Program: An AIAA Assessment*, 1987

"As revealed in a recent national survey of student achievement, an estimated 90 percent of America's high school graduates may not be capable of accomplishing even the most routine high-technology tasks in the future. While up to 90 percent of high school graduates in other countries enjoy a proficiency in math and science, a mere 6 percent of U.S. graduates attain the same aptitudes. . . . This challenge exists at every level from elementary through graduate education." *Pioneering the Space Frontier*, 1986

"Thus, a strong educational system is an essential component of a vital science without which scientific progress would come to a rapid halt. It is most important to ensure that students are being broadly educated in concepts and skills which will be useful throughout their careers." *The Crisis in Space and Earth Science*, 1986

"The future of space biology and medicine will depend on the quality of the young people attracted to the field. NASA should expand its fellowship programs to encourage predoctoral and postdoctoral training at Universities, research institutes, and NASA research centers. Even in a period of reduced flight opportunities, there is exciting important research to be done in ground-based laboratories." *A Strategy for Space Biology and Medical Science*, 1987

ADDITIONAL STUDIES

Several studies provided significant inputs to the work described in this report. Brief synopses of the studies are provided below.

Study: *The Next Giant Leap in Space: An Agenda for International Cooperation*

Sponsor: The United Nations Association of the U.S.A.

Objectives: As part of the UNA-USA's Multilateral Project, to provide an opportunity for private citizens to participate in an examination of the possibilities for international cooperation in the peaceful uses of space; to examine programs and policy options and to develop a list of recommendations for the U.S. to pursue.

Study: *The Crisis in Space and Earth Science*

Sponsor: Space and Earth Science Advisory Committee, NASA Advisory Council

Objectives: To determine the nature of the changes under way in the environment of Space and Earth Science programs; to understand the implications of those changes and to make recommendations to enable NASA to proceed with a long-term, productive program in Space and Earth Sciences; to develop a more rational process for making decisions, especially concerning the selection of major new initiatives; to determine how to optimize the use of limited available resources in such a way as to construct the best possible scientific program.

Study: *NASA Mixed Fleet Study*

Sponsor: Office of Space Flight, NASA Headquarters

Objectives: To formulate an overall NASA mixed fleet launch strategy and policy for the periods 1988-1995 and 1995-2010. The tasks included an assessment of mission needs; a launch vehicle data base; launch vehicle/payload capture analysis; mixed fleet scenario definition; and mixed fleet strategy and policy.

Study: *NASA Life Sciences Working Group*

Sponsor: Administrator's Long Range Planning Office, NASA Headquarters

Objectives: To identify the specific questions which must be answered in the life sciences related to humans in long-duration space flight; to outline the research program required to resolve each issue; to assess NASA's program in terms of the emphasis currently given to each issue.

Study: *National Commission on Space Privatization Issues*

Sponsor: Aerospace Industries Association of America, Inc.

Objectives: To develop criteria to decide where, in the National Commission on Space road map, industry is likely to desire privatization; to identify most attractive candidates in NCOS report for privatization; to suggest NASA actions and ground rules which will increase industry interest in privatization.

Study: *U.S. Civil Space Program: An AIAA Assessment*

Sponsor: American Institute of Aeronautics and Astronautics

Objectives: To conduct an analysis and detailed discussion of both urgent (near-to-mid-term) and selected long-term issues affecting the U.S. civil space program. Four categories of issues were addressed: restoring momentum, maintaining space leadership, organizing and managing the civil space program, and building for the future.

Study: *Task Force on Issues of a Mixed Fleet of Launch Systems*

Sponsor: NASA Advisory Council

Objectives: To examine the issues and questions, and make recommendations to NASA concerning a new policy to conduct the nation's space flight program with a mixed fleet of vehicles. The Task Force addressed three principal issues: an appropriate mix of Shuttle and expendable launch vehicles; appropriate policies and practices for NASA to use in planning and providing launch services; the role NASA should play with respect to current efforts to promote further commercialization of space launch services.

Study: *Assessment of the Soviet Space Program*

Sponsor: Administrator's Long Range Planning Office, NASA Headquarters

Objectives: To undertake a technical review of the capabilities of the Soviet space program to include transportation and launch systems, piloted programs, and space science programs.

Study: *Task Force on Space Program Goals*

Sponsor: NASA Advisory Council

Objectives: To assess the work conducted by NASA to respond to the National Commission on Space report and advise in the formulation of any plans, with the emphasis on nearer-term goals, objectives, program thrusts, and broad policy issues identified by the task force.

Study: *Microgravity Materials Science Assessment Task Force*

Sponsor: Administrator's Long Range Planning Office, NASA Headquarters

Objectives: To determine NASA's role in research, technology development, and hardware development; to identify essential areas of research; to assess NASA's roles in assisting its customers interested in the STS; to develop a plan for using the Shuttle, Spacelab, free-flyers, and Space Station for microgravity processing research.

Study: *A Strategy for Space Biology and Medical Science*

Sponsor: Space Science Board, National Academy of Sciences

Objectives: To develop a strategy for space biology and medical science for the 1980s and 1990s; to identify and describe those areas of fundamental scientific investigation in space biology and medicine that are both exciting and important to pursue; to develop the foundation of knowledge and understanding that will make long-term piloted space habitation and/or exploration feasible.

Study: *Educational Affairs Five-Year Plan*

Sponsor: Educational Affairs Division, NASA Headquarters

Objectives: To develop a five-year plan to improve the quality of science, mathematics, and technology education in the nation's school systems and increase the talent pool of professional and technical personnel needed in the fields of aeronautics and space.

Study: *Committee on Space Technology Needs for the Future*

Sponsor: Aeronautics and Space Engineering Board, National Academy of Sciences

Objectives: To identify enabling and enhancing technology required to support an aggressive civilian space program for the next 30 years, considering both mission goals and the need for reduced costs for acquisition and operations in space; review probable sets of space science, military, space applications, and piloted exploration missions; identify technologies needed to realize and support the defined missions; identify areas where new and innovative approaches are likely to produce exceptional systems, benefits, or new capabilities; define and prioritize a research and technology development program and identify projects and in-space research and technology needs to bring the necessary technology to a state of readiness.

Study: *Space Science in the Twenty-First Century: 1995-2015*

Sponsor: Space Science Board, National Academy of Sciences

Objectives: To identify the major directions for space science for the years 1995-2015. The study was devoted to the review of six major discipline groups: Fundamental Physics and Chemistry, Planetary/Lunar Exploration, Astronomy/Astrophysics, Earth Sciences, Solar/Space Plasmas, and Life Sciences.

Study: *OSTP Comments and Recommendations on the National Commission on Space*

Sponsor: Office of Science and Technology Policy, NASA Headquarters

Objectives: To develop a strategy on how to respond to the recommendations contained in the National Commission on Space report. This is intended to include a review of the current space-related policies and directives, as well as to develop Presidential direction to appropriate agencies to examine the Report and develop potential implementation plans.

Study: *Task Force on International Policy and Program Issues*

Sponsor: NASA Advisory Council

Objectives: To consider the long-range plans of NASA, other nations, and international bodies, with emphasis on opportunities for cooperative activities and alternative forms of such cooperation, as well as areas of present and potential competition; consider the use of international activities as instruments of foreign policy.

Study: *Life Science Strategic Planning Study Committee*

Sponsor: NASA Advisory Council

Objectives: Characterize present NASA life science programs; recommend major NASA life science research goals and objectives; project foreseeable progress in relevant life sciences and technologies; determine what research and development should be supported; formulate technical and scientific strategies to accomplish the selected objectives and goals.

Study: *National Space Transportation and Support Study*

Sponsor: Office of Space Flight, NASA Headquarters; Department of Defense

Objectives: To study the development of a second-generation space transportation system—making use of piloted and automated systems to meet the requirements of all users. A full range of options will be studied, including Shuttle-derived technologies and others. The study will examine the 1995-2010 time frame.

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